(NASA-CR-148459) TC-2 POST HELIOS EXPERIMENT DATA REVIEW (General Dynamics/Convair) 298 p HC $9.25 CSCL 21H

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TC-2 POST HELIOS EXPERIMENT DATA REVIEW AT NASA-LeRC

31 October 1975

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TC-2 POST HELIOS EXPERIMENT DATA REVIEW

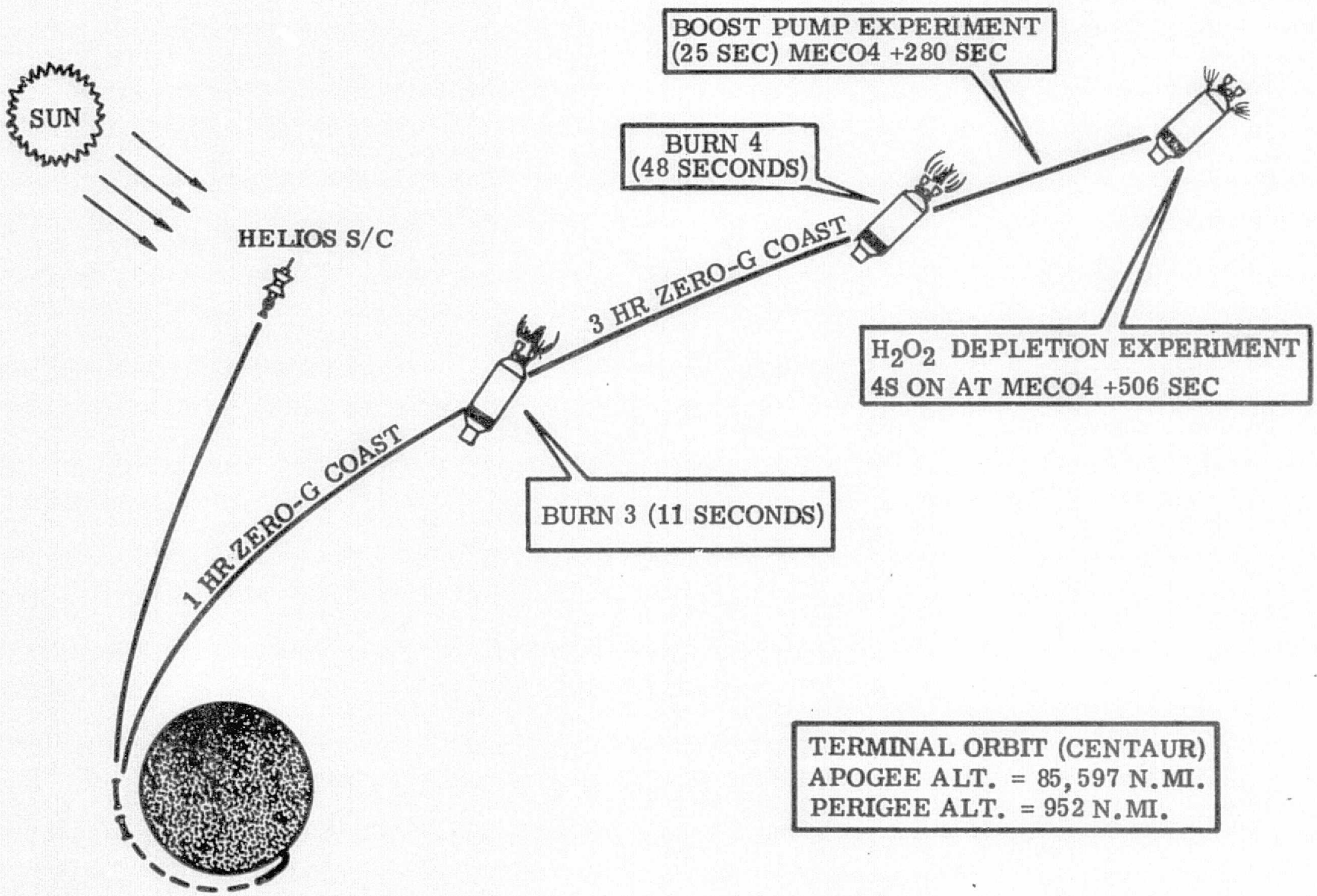
TC-2 CENTAUR MISSION OBJECTIVES

PRIMARY – INJECT TE-M-364-4/HELIOS STAGE.

SECONDARY – PERFORM POST-HELIOS CENTAUR EXTENDED FLIGHT PROPELLANT MANAGEMENT AND PROPULSION EXPERIMENTS.

- DEMONSTRATE CENTAUR CAPABILITY TO PERFORM OPERATIONAL 2-BURN MISSION WITH EXTENDED ZERO-G PARKING ORBIT COAST.
- OBTAIN DATA TO EVALUATE:
  - ▲ CENTAUR CAPABILITY TO ACCOMPLISH AN OPERATIONAL 3-BURN SYNC. ORBIT MISSION.
  - ▲ PROPELLANT BEHAVIOR DURING ZERO-G COAST OPERATIONS AND SETTLING REGIMES.
  - ▲ TANK PRESSURE PROFILES FROM COAST PHASE ENVIRONMENTS AND OPERATIONS AND PRESSURIZATION PHASES.
  - ▲ COMPONENT THERMAL HISTORIES AND THERMAL CONTROL TECHNIQUES.
  - ▲ REACTION CONTROL THRUST SYSTEM PROPELLANT SETTLING AND VEHICLE CONTROL PERFORMANCE (AND H_2O_2 CONSUMPTION).
  - ▲ PROPULSION RESTART SEQUENCES.
  - ▲ BOOST PUMP PERFORMANCE.

TC-2 POST HELIOS EXPERIMENT



TC-2 POST-HELIOS EXPERIMENT – SUMMARY OF SEQUENCES/SIGNIFICANT EVENTS

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	EVENT	TIME (SEC)
COAST 2		
1.0 HR. ZERO-G (MECO2 RESIDUALS = 5185 LB)	TE-M-364-4/CENTAUR SEP'N AND CENTAUR RETROTHRUST GHe BLOWDOWN	MECO2 + 72
	START ORIENT TO -R VECTOR	+ 116
	CCVAPS VENT CONTROL ON	+ 300
	SELECT HIGH-GAIN ANTENNA	+ 33.3 MIN
BURN 3	2-S ON (START SETTLING)	MES3 - 420
11 SECS FIXED	4-S ON	- 120
(MECO3 RESIDUALS	CCVAPS PRESS'N ON	- 43
= 4399 LB)	BOOST PUMP START	- 28
	PRE-START	- 17
	MES3	0
COAST 3	P&Y H_2O_2 ENGINE WARMING FIRING	MECO3 + 120 SEC
3 HRS. ZERO-G	INITIATE THERMAL ROLL	MECO3 + 28, 56, 84, 112, 140, & 168 MIN
	S-H_2O_2 ENG. WARMING FIRING	MES3 + 50 & 100 MIN
	REDUCE ALLOWABLE ATTITUDE ERRORS	MECO3 + 120 MIN
	INITIATE PROGRAMMED VENT	MECO3 + 143 MIN
BURN 4	2-S ON (START SETTLING)	MES4 - 420
48 SEC'S	4-S ON	- 120
WEIGHT CUT-OFF	CCVAPS PRESS'N ON	- 43
(MECO4 RESIDUALS	BPS	- 28
= 1094 LB)	PRESTART	- 24
	MES4	0

TC-2 POST-HELIOS EXPERIMENT – SUMMARY OF SEQUENCES/SIGNIFICANT EVENTS

	EVENT	TIME (SEC)		
COAST 4 27 MINS. (MECO . TO UN- LOCK VENT VALVES)	CCVAPS PRESS'N ON	MECO4 + 10		
	CCVAPS PRESS'N OFF	110		
	4-S ENG'S ON	200	BOOST PUMP EXPERIMENT	
	BOOST PUMP START	280		
	PRESTART VALVES OPEN	300		TANK BLOWDOWN EXPER'T
	BOOST PUMPS OFF	305		
	4-S ENG'S OFF	306		
	PRESTART VALVES CLOSED	505		
	4-S ENG'S ON	506	H_2O_2 DEPLETION EXPER'T	
	4-S ENG'S OFF	1606		
	UNLOCK VENT VALVES	1610		

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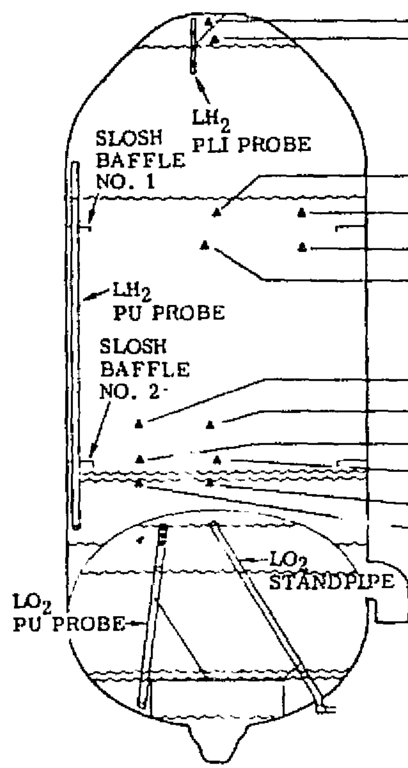
TC-2 POST HELIOS EXPERIMENT DATA REVIEW

LIQUID-VAPOR SENSOR LOCATIONS



MEASUREMENT NUMBER	LOCATION	
	STATION	RADIAL
CM241X	2485	310
CM242X	2473	340
CM320X	2410	182
CM319X	2410	62
CM247X (1)	2393	70
CM248X (1)	2393	190
CM252X	2320	310
CM251X	2320	190
CM254X	2309	302
CM253X	2309	182
CM255X	2302	190
CM256X	2302	310

NOTES: (1)

L-V SENSOR MOUNTED PARALLEL TO LONGITUDINAL AXIS. ALL OTHER SENSORS INSTALLED NORMAL TO LONGITUDINAL AXIS.

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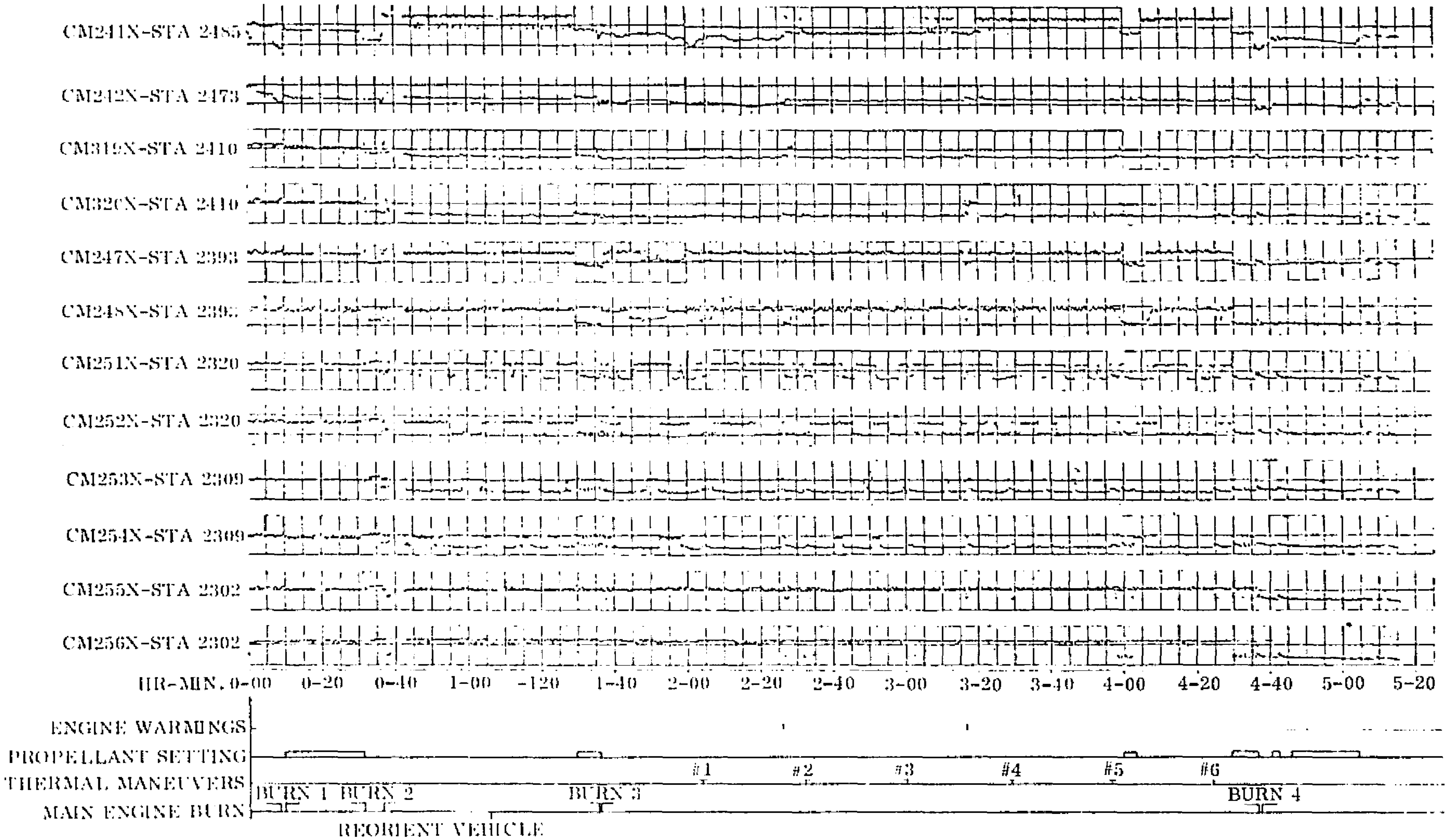
LH_2 PROPELLANT BEHAVIOR DURING TC-2 MISSION



CENTAUR SECOND COAST (LO_2 TANK)

- PAYLOAD SEPARATION OCCURRED AT MECO2 +72 SEC FOLLOWING RETRO-BLOWDOWN. REORIENTATION OF THE CENTAUR WAS INITIATED AT MECO2 +116 SEC. A ONE-HOUR NEAR ZERO-G COAST FOLLOWED.

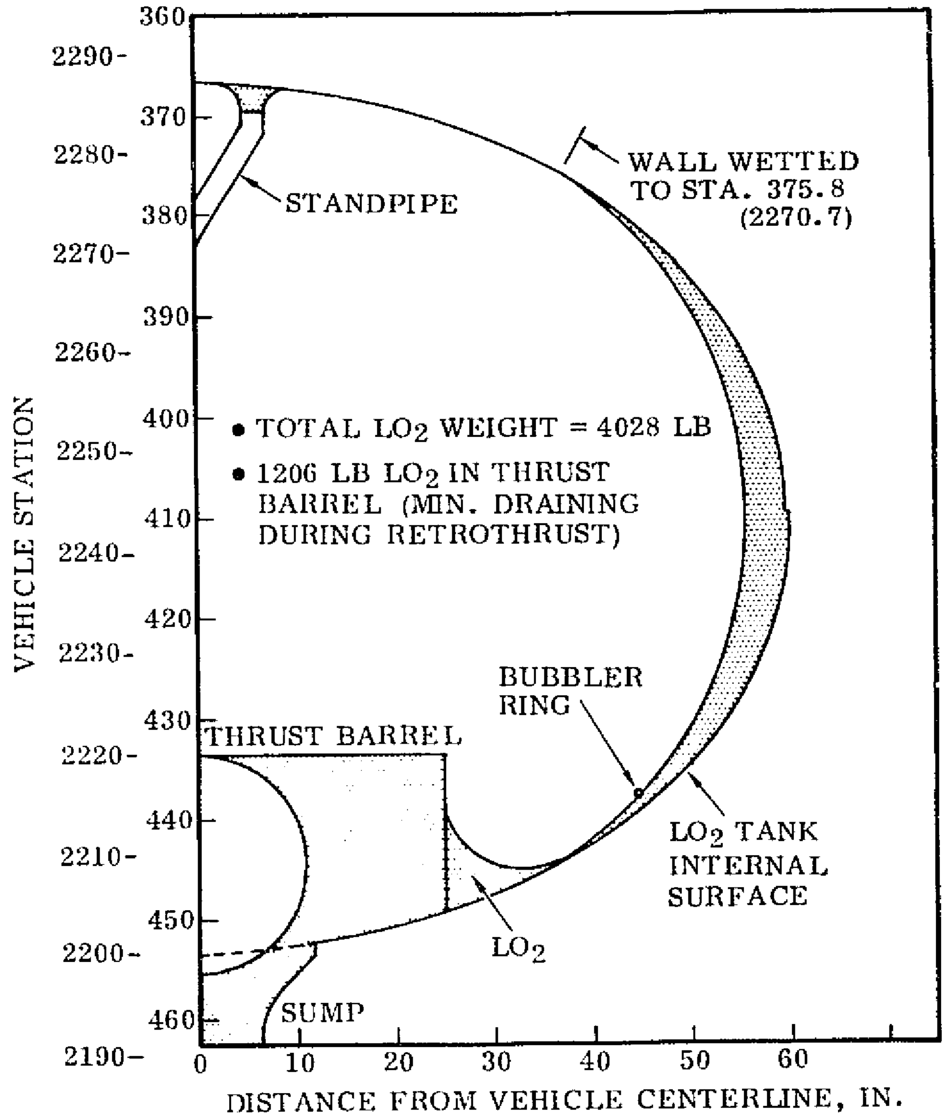
- ANALYSIS INDICATES THAT BETWEEN 15% AND 30% OF THE LO_2 IN THE THRUST BARREL DRAINED OUT DURING THE RETRO-BLOWDOWN MANEUVER.

- AFTER THE RETRO-BLOWDOWN MANEUVER, THE LO_2 FORCED FORWARD WOULD BEGIN TO REORIENT IN ORDER TO MINIMIZE LIQUID PRESSURE. LIQUID PRESSURE AT THE NEAR ZERO-G LEVEL IS SURFACE TENSION DOMINATED.

- THE STEADY STATE LO_2 ORIENTATION WHICH WOULD EVENTUALLY BE REACHED IS SHOWN. THIS CONFIGURATION ASSUMES MINIMUM DRAINING OF THE THRUST BARREL.

- IT IS BELIEVED THAT THE STANDPIPE ENTRY AND BUBBLER RING WERE IMMERSED IN LO_2 THROUGHOUT COAST.

TC-2 2ND COAST STEADY STATE LO_2 PROPELLANT CONFIGURATION



CENTAUR SECOND COAST (LH_2 TANK)

- IMMEDIATELY FOLLOWING MECO2, FORWARD MOVEMENT OF LH_2 WAS INDICATED BY PROGRESSIVE WETTING OF L-V SENSORS AS TABULATED BELOW:

	SENSOR STA.	TIME WETTED REFERENCED TO MECO2
CM248X	2393	10 SECONDS
CM247X	2393	18 SECONDS
CM319X	2410	37 SECONDS
CM241X	2485	62 SECONDS

- DURING THIS COAST, CM241X WAS WET 90% OF THE TIME WHILE CM242X WAS CONTINUOUSLY DRY INDICATING THAT, ALTHOUGH A SIGNIFICANT AMOUNT OF LH_2 WAS FORCED FORWARD, THE MAJORITY REMAINED AFT.

- THE L-V SENSORS JUST BELOW THE FORWARD SLOSH BAFFLE (CM247/8X) SHOWED WET THROUGHOUT THE ZERO-G PORTION OF THE COAST. THIS IS EXPLAINED BY CONSIDERING THE SLOSH BAFFLE MICROSCOPICALLY (I.E., ROUNDED EDGES WHICH SATISFY A ZERO CONTACT ANGLE WITH LARGER QUANTITIES OF LH_2). THE MAXIMUM QUANTITY WHICH CAN BE CONTAINED AT THE SLOSH BAFFLE IS 39.4 FT^3. THE QUANTITY REQUIRED TO JUST WET CM247/8X IS 37.2 FT^3.

- THE L-V SENSORS JUST ABOVE THE AFT SLOSH BAFFLE (CM251/2X) INDICATED WET 75% OF THE TIME WHILE THOSE MOUNTED ON THE SLOSH BAFFLE (CM253/4X) WERE WET 25% OF THE TIME. THIS BEHAVIOR IS BELIEVED TO BE CAUSED BY DISTURBANCE OF THE LH_2 SETTLED AFT ABOUT A STEADY STATE CONFIGURATION AS SHOWN.

TC-2 LH_2 TANK STEADY STATE PROPELLANT BEHAVIOR (SECOND COAST)

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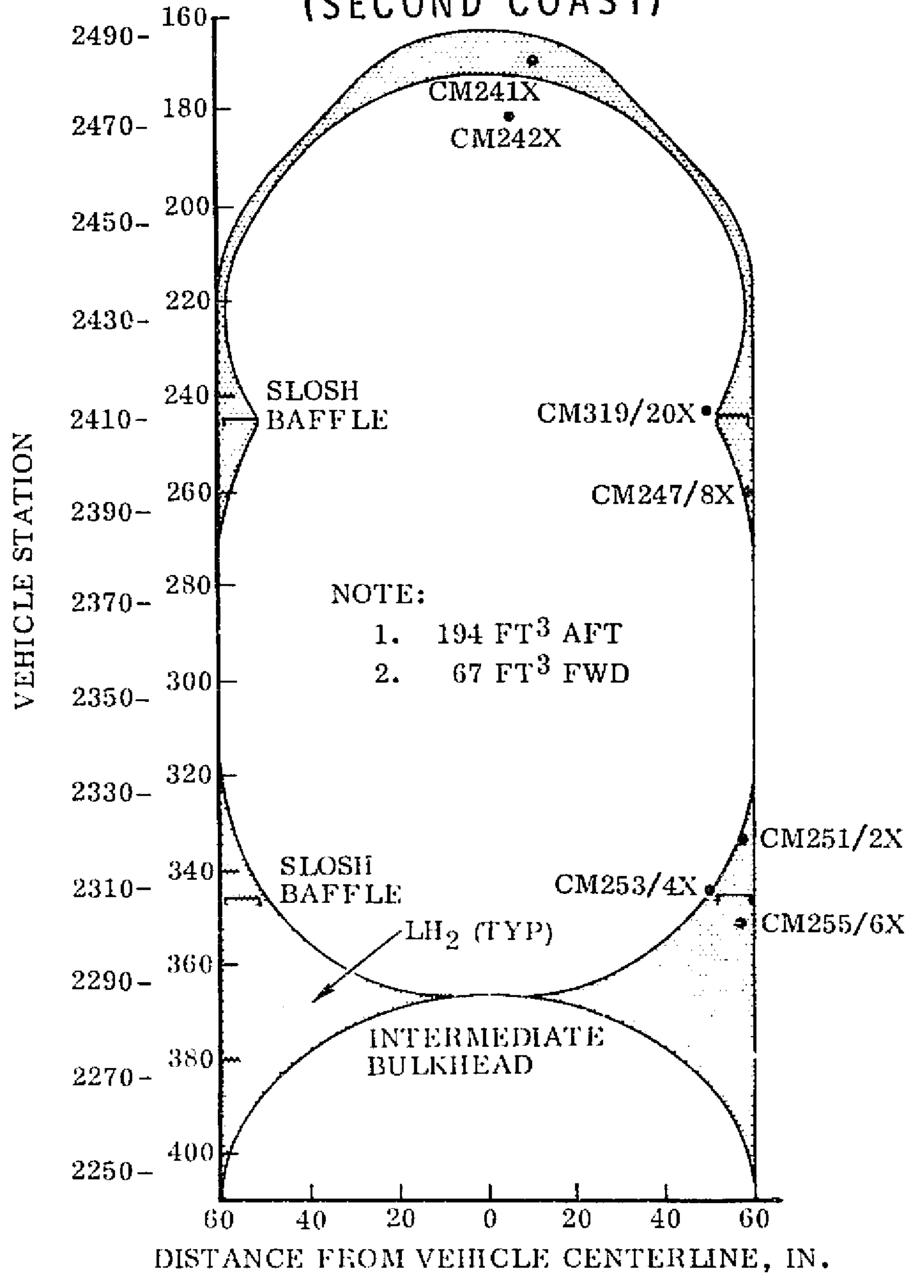


CENTAUR THIRD COAST (LO_2 TANK)

- FOLLOWING MECO3, VEHICLE ACCELERATION DROPS IMMEDIATELY TO $\approx 10^{-8}$g RESULTING IN PROPELLANT REORIENTATION TO MINIMIZE LIQUID PRESSURE.

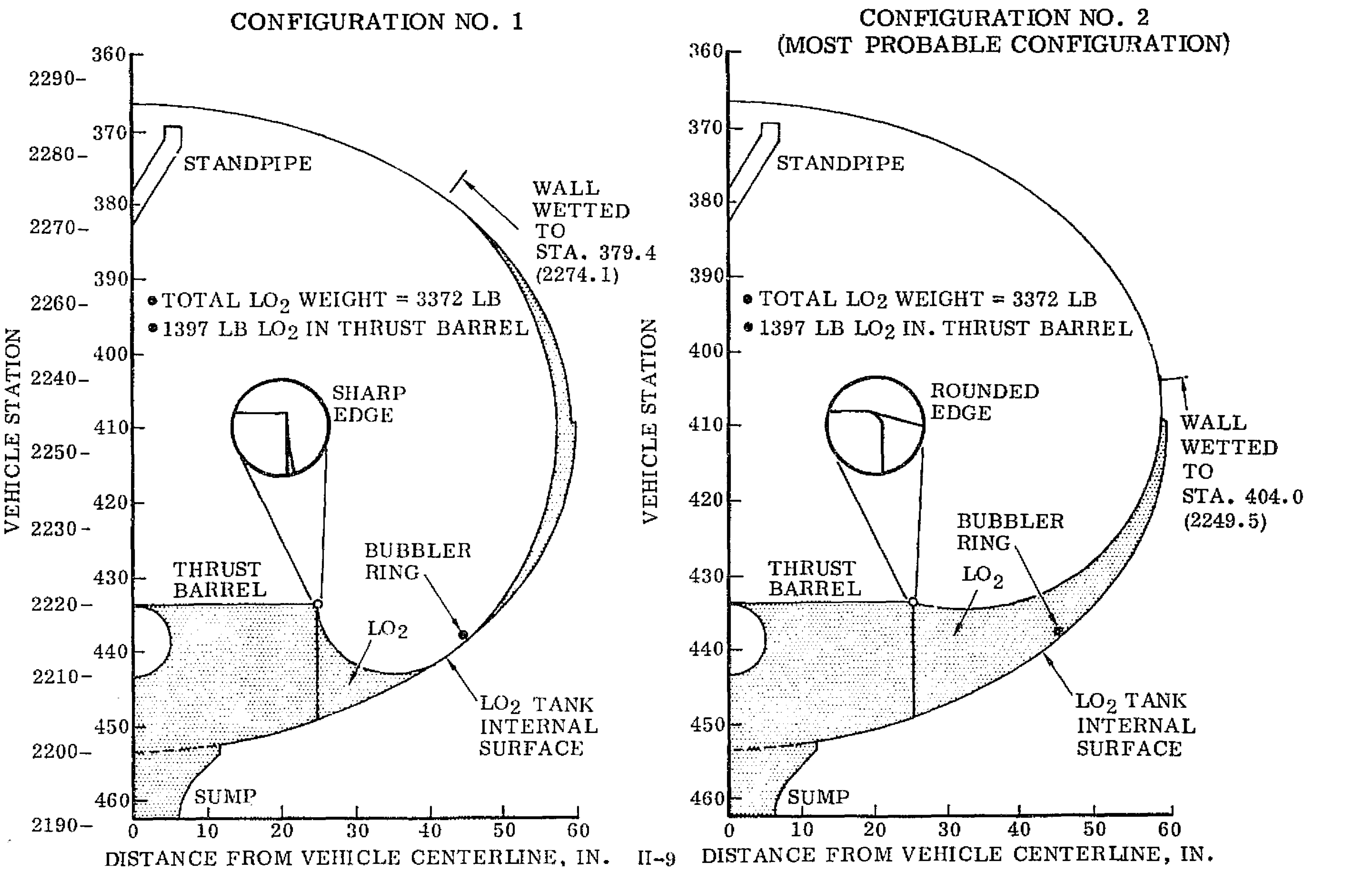
- AT MECO3 THE LO_2 LEVEL IS SLIGHTLY BELOW THE TOP OF THE THRUST BARREL. A SPHERICAL GAS BUBBLE WILL BE TRAPPED WITHIN THE THRUST BARREL AND DRAINING WILL NOT OCCUR.

- DUE TO THE QUANTITY OF LO_2 AND TANK GEOMETRY THERE ARE TWO POSSIBLE STEADY STATE CONFIGURATIONS FOR THE LO_2 OUTSIDE THE THRUST BARREL.

  - FIRST, THE CONFIGURATION CAN BE COMPRISED OF A FILLET BETWEEN THE OUTSIDE SURFACE OF THE THRUST BARREL AND THE TANK WALL WITH THE REMAINDER ORIENTED AT THE SIDE OF THE TANK. THIS CONFIGURATION, TOGETHER WITH THE SECOND, AND MOST PROBABLE ORIENTATION, IS DEPICTED.

  - THE SECOND CONFIGURATION IS JUDGED MOST PROBABLE SINCE IT WOULD HAVE TO BE PASSED THROUGH TO ACHIEVE THE FILLET/SIDE ORIENTED CONFIGURATION. THIS, OF COURSE, MUST HAPPEN IF THE RIM OF THE THRUST BARREL IS A PERFECTLY SHARP EDGE IN ORDER TO ACHIEVE A ZERO CONTACT ANGLE. FROM A MICROSCOPIC STANDPOINT, HOWEVER, THE THRUST BARREL RIM CANNOT BE PERFECTLY SHARP AND A ZERO CONTACT ANGLE CAN BE ACHIEVED AS DEPICTED IN THE INSERT.

TC-2 3RD COAST STEADY STATE
LO_2 PROPELLANT CONFIGURATION



CENTAUR THIRD COAST (LH_2 TANK)

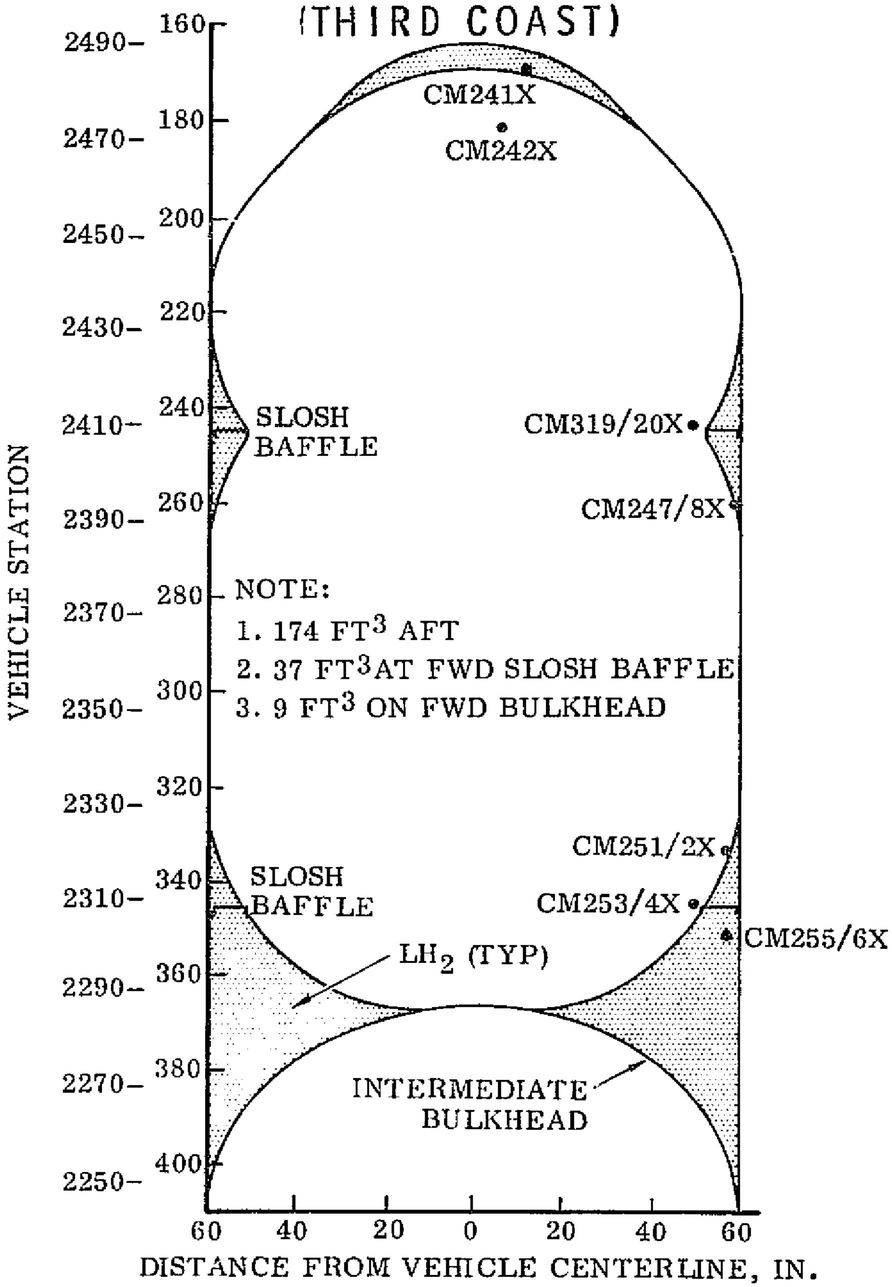
- OF SIGNIFICANCE IN THE LH_2 TANK WAS THE DRY INDICATION OF THE FORWARDMOST L-V SENSOR (CM241X) BETWEEN MECO3 AND THE FIRST "S" ENGINE WARMING ($\approx$ 50 MIN.) INDICATING LITTLE, IF ANY, LH_2 FORCE FORWARD DURING THE MECO TRANSIENT.

- FOLLOWING THE FIRST "S" ENGINE WARMING HOWEVER, CM241X SHOWED WETTING. FURTHER WETTINGS WERE NOTED FOLLOWING SUBSEQUENT "S" ENGINE WARMING/THERMAL ROLL ACTIVITIES. UNEXPLAINED IS THE REWETTING OF THIS SENSOR IMMEDIATELY FOLLOWING THE PLANNED VENT. APPARENTLY SOME LH_2 REMAINED IN THE VICINITY OF THE FORWARD DOOR THROUGH THE SETTLING/PLANNED VENT EVENTS.

- AS DURING THE SECOND COAST THE L-V SENSORS JUST BELOW THE FORWARD SLOSH BAFFLE (CM247/8X) INDICATED PREDOMINATELY WET AGAIN IMPLYING APPROXIMATELY 37-39 FT^3 OF LH_2 ATTACHED AT THE SLOSH BAFFLE.

- THE L-V SENSORS JUST ABOVE THE AFT SLOSH BAFFLE (CM251/2X) INDICATED WET 50% OF THE TIME WHILE THOSE MOUNTED ON THE SLOSH BAFFLE (CM253/4X) WERE WET 12% OF THE TIME. THIS BEHAVIOR IS BELIEVED TO BE CAUSED BY DISTURBANCE OF THE AFT POSITIONED LH_2 ABOUT A STEADY STATE CONFIGURATION AS SHOWN.

TC-2 LH_2 TANK STEADY STATE PROPELLANT BEHAVIOR (THIRD COAST)



SUMMARY

LO_2 TANK

- LO_2 TANK INTERNAL CONFIGURATION IS SUCH THAT LIQUID DISTRIBUTION FAVORED COLLECTION ABOUT THE THRUST BARREL AND THE TANK MIDSECTION.
- LIQUID DISTRIBUTION ENHANCED PROPELLANT COLLECTION.
- THERE WAS NO QUENCH PRESSURE INCREASE DURING PROPELLANT SETTLING BECAUSE THE AFT BULKHEAD REMAINED WETTED DURING COAST.
- IT IS BELIEVED THAT VEHICLE DISTURBANCES (S-MOTOR WARMING FIRINGS, THERMAL MANEUVERS, ETC.) HAD LITTLE INFLUENCE ON THE LO_2 DISTRIBUTION.
- HELIUM BUBBLER PURGE PROBABLY FLOWED THROUGH A THIN FILM OF LO_2 FOR BOTH ZERO-G COASTS.
- THE STANDPIPE AND PRESSURE SENSE LINE PURGE EXITS WERE IMMERSED IN LO_2 FOR THE ONE HOUR COAST, AND WERE CLEAR OF LO_2 DURING THE THREE HOUR COAST.

LH_2 TANK

- LH_2 TANK INTERNAL CONFIGURATION IS SUCH THAT LIQUID DISTRIBUTION FAVORED COLLECTION ABOUT THE INTERMEDIATE BULKHEAD.
- LIQUID DISTRIBUTION ENHANCED PROPELLANT COLLECTION.
- THERE WAS NO QUENCH PRESSURE INCREASE DURING PROPELLANT SETTLING BECAUSE THE INTERMEDIATE BULKHEAD AND FORWARD BULKHEAD REMAINED WETTED DURING COAST.
- VEHICLE DISTURBANCES (S-MOTOR WARMING FIRINGS, THERMAL MANEUVERS, ETC.) HAD LITTLE INFLUENCE ON THE LH_2 DISTRIBUTION.

SUMMARY (Contd)

TC-5 APPLICATION

- NO PROBLEMS ARE ANTICIPATED IN COLLECTING PROPELLANTS FOLLOWING THE 5 1/4-HOUR ZERO-G COAST.
- PROPELLANT TANK VENTING PRIOR TO MES3 WILL BE GREATER IN MAGNITUDE THAN EXPERIENCED DURING PREPROGRAMMED VENT. NO PROBLEMS ARE ANTICIPATED IN MAINTAINING PROPELLANT CONTROL DURING VENTING.
- THE 30-MINUTE AND 20-MINUTE ZERO-G COAST PERIODS FOLLOWING MECO3 AND MECO4, RESPECTIVELY, SHOULD HAVE THE LO_2 AND LH_2 COLLECTED AFT PRIOR TO PROPELLANT SETTLING.
- LO_2 AND LH_2 SHOULD REMAIN COLLECTED AFT DURING THE 2-HOUR ZERO-G COAST FOLLOWING MECO6. NO PROBLEMS ARE EXPECTED DURING THE MID-COAST VENT PERIOD.

TC-2 POST HELIOS EXPERIMENT DATA REVIEW

HELIUM USAGE

- PURGES
- H_2O_2 EXPULSION
- MAIN ENGINES
- PROPELLANT TANK PRESSURANT

PURGES

- LH_2 TANK ENERGY DISSIPATOR
  2032 SCCM (MEASURED) USAGE TO MECO 4 = 0.2062 LB.
- LO_2 TANK BUBBLER
  576.6 SCCM (MEASURED) USAGE TO MECO 4 = 0.0576 LB.
- LO_2 TANK STANDPIPE
  1773.7 SCCM (MEASURED) USAGE TO MECO 4 = 0.1800 LB.
- LO_2 TANK PRESS. SENSE LINE
  425.7 SCCM (MEASURED) USAGE TO MECO 4 = 0.0432 LB.
- H202 SYSTEM PURGE
  251 SCIM (MEASURED) USAGE TO MECO 4 = 0.4175 LB.

MAIN ENGINES

- ENGINE START
  0.088 LB/START USAGE TO MECO 4 = 0.352 LB.
- PURGE
  26.2 SCCM USAGE TO MECO 4 = 0.003 LB.

H202 EXPULSION

0.00230 LB HELIUM/LB H2O2 EXPELLED

- 182.6 LB. H202 CONSUMED TO MECO2
- 330.9 LB. H202 CONSUMED TO MECO4

- 0.420 LB. HELIUM REQUIRED FOR H202 EXPULSION TO MECO2
- 0.761 LB. HELIUM REQUIRED FOR H2O2 EXPULSION TO MECO4

ACCUMULATED HELIUM USAGES

- HELIUM TOTAL TO MECO2 + 72 SECONDS = 0.718 LB.
  (CENTAUR RETRO IS EFFECTED VIA BLOWDOWN OF SMALL HELIUM BOTTLE)

- HELIUM TOTAL TO MECO4 = 2.018 LB.

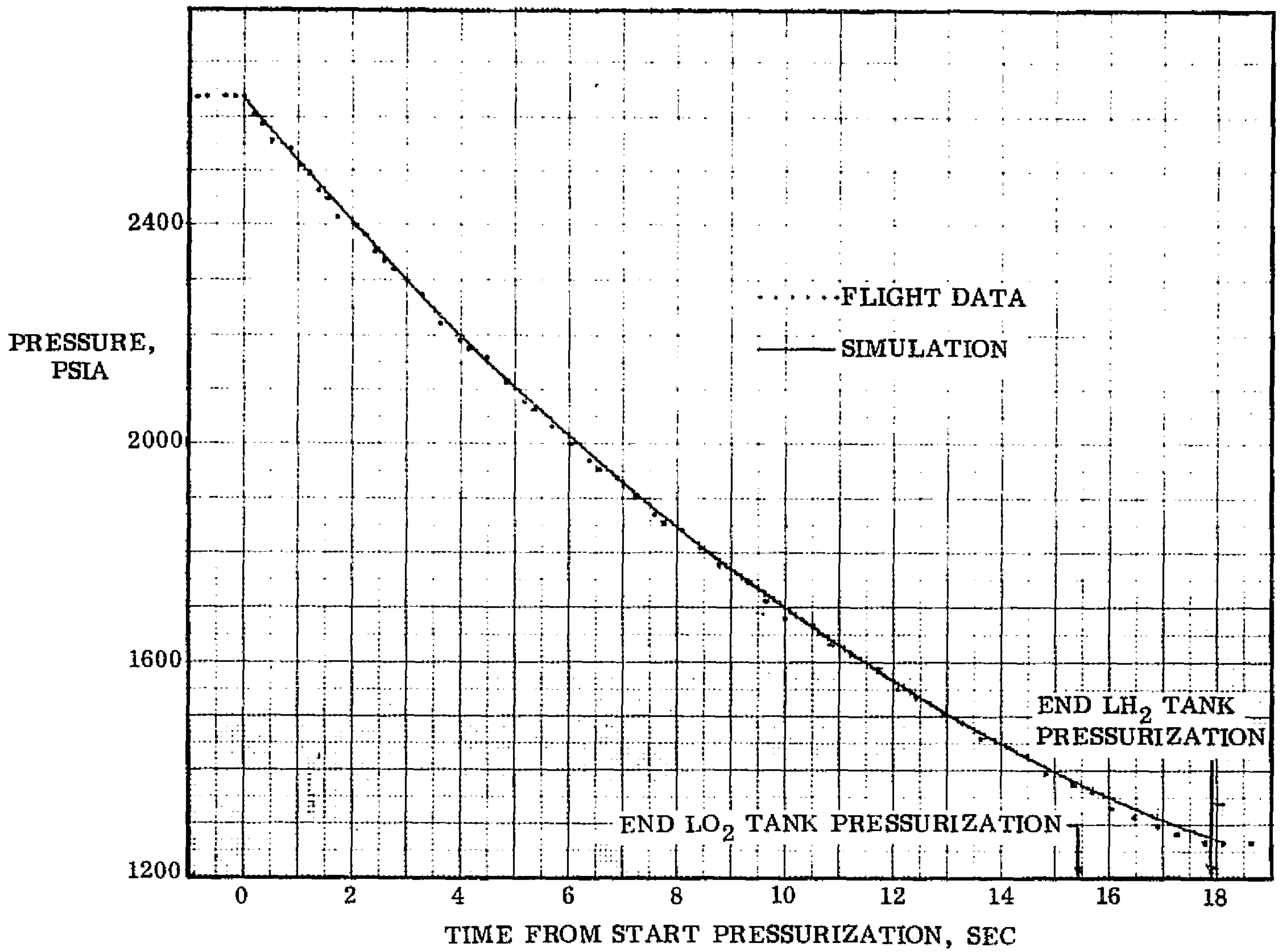
PROPELLANT TANK PRESSURANT

- USAGES OBTAINED FROM HELIUM BOTTLE BLOWDOWN MODEL
- SOLENOID VALVE ON-TIMES ACCURATELY KNOWN
- ACCURACY OF BOTTLE BLOWDOWN VERIFIED BY PRE-MES3 AND PRE-MES4 PRESSURIZATION SIMULATIONS

PRE-MES3 PRESSURIZATION

- INITIAL CONDITIONS: P = 2639 PSIA, T = 505°R
  H2 ORIFICE DIA. = 0.0995 INCHES
  O2 ORIFICE DIA. = 0.0465 INCHES
- LH2 TANK VALVE TOTAL ON-TIME = 18.28 SECONDS
- LO2 TANK VALVE TOTAL ON-TIME = 18.06 SECONDS
- FIGURE SHOWS GOOD MATCH BETWEEN PREDICTIONS AND CF2P.
- PRESSURE MATCH WAS OBTAINED WITH NOMINAL ORIFICE DISCHARGE COEFFICIENTS OF 0.81.
- NO ATTEMPT MADE TO MATCH BOTTLE TEMPERATURE (CF4T) DUE TO ITS POOR TEMPERATURE RESPONSE.

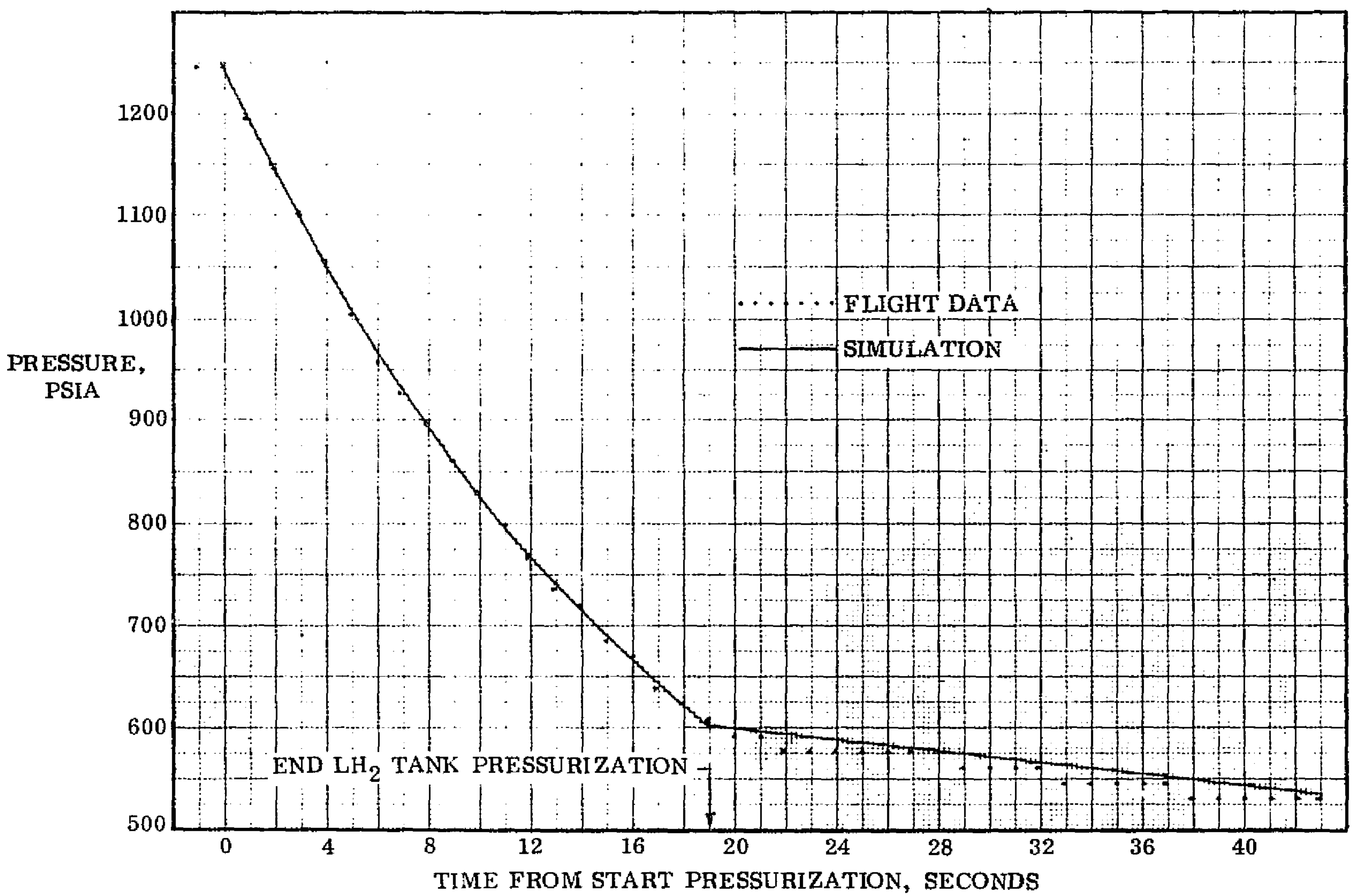
TC-2 HELIUM BOTTLE PRESSURES DURING THIRD PRESSURIZATION



PRE-MES4 PRESSURIZATION

- INITIAL CONDITIONS: P = 1247 PSIA, T = 477°R
  H2 ORIFICE DIA. = 0.0995 INCHES
  O2 ORIFICE DIA. = 0.0465 INCHES
- LH2 TANK VALVE TOTAL ON-TIME = 19.02 SECONDS
- LO2 TANK VALVE TOTAL ON-TIME = 42.76 SECONDS
- FIGURE SHOWS GOOD MATCH BETWEEN PREDICTIONS AND CF2P.
- PRESSURE MATCH WAS OBTAINED WITH NOMINAL ORIFICE DISCHARGE COEFFICIENTS OF 0.81.
- NO ATTEMPT MADE TO MATCH BOTTLE TEMPERATURE (CF4T) DUE TO ITS POOR TEMPERATURE RESPONSE

TC-2 HELIUM BOTTLE PRESSURES DURING FOURTH PRESSURIZATION



SUMMARY OF MISSION HELIUM USAGES

- TABLE CONTAINS HELIUM PRESSURANT USAGES AND PRE-FLIGHT PREDICTIONS
- WITH EXCEPTION OF FIRST AND SECOND LO2 TANK PRESSURIZATIONS, USAGES WERE WITHIN PREDICTION BAND.
- HELIUM USAGES FROM LIFTOFF TO CENTAUR RETRO ARE:

PURGES + MAIN ENGINE + H2O2 EXPULSION	=	0.718 LB
PROPELLANT TANK PRESSURIZATION	=	1.718 LB
		2.436 LB

BOTTLE CONDITIONS SHOW 15.00 LB - 12.63 LB = 2.37 LB

- HELIUM EXPELLED DURING CENTAUR RETRO = 4.79 LB (P=2764 PSIA, T = 530°R)
- HELIUM USAGES FROM CENTAUR RETRO TO MECO4 ARE:

PURGES + MAIN ENGINE + H2O2 EXPULSION	=	1.300 LB
PROPELLANT TANK PRESSURIZATION	=	4.339 LB
		5.639 LB.

- HELIUM REMAINING AT MECO4 IS:

15.00	LB (INITIAL LOAD)
- 2.436	LB
- 4.790	LB
- 5.639	LB
2.135	LB

BOTTLE CONDITIONS SHOW 2.25 LB (P = 637 PSIA, T = 438°R)

TC-2 MISSION HELIUM USAGE HISTORY

EVENT	TIME FROM T=0, SEC.	HELIUM BOTTLE CONDITIONS(1) PSIA	°R	LB.	PRESSURANT USAGE, LB. LH_2 TANK	LO_2 TANK	PREDICTED PRESSURANT USAGE, LB. LH_2 TANK	LO_2 TANK
T-0	0	3453	539	15.00				
INITIATE PRE-MES1 PRESS'N	437	3437	537	14.99	0.557	0.166	0.581±.106	0.129±.024
MES1	483.2	3152	NOT VALID	-				
MECO1	584.0	3183	526	14.23				
INITIATE PRE-MES2 PRESS'N	1859.8	3101	520	13.84	0.834	0.161	0.81 ± .08	0.091±.028
MES2	1897.8	NO DATA	NO DATA	NO DATA				
MECO2	2244.3	2749	509	12.63				
INITIATE PRE-MES2 PRESS'N	5730.0	2639	505	7.60	2.105	0.571	2.409±.254	0.656±.208
MES3	5773.0	1247	NOT VALID	-				
MECO3	5784.0	1341	416	4.85				
INITIATE PRE-MES4 PRESS'N	16541.5	1247	477	3.97	1.096	0.567	0.912±.162	0.476±.082
MES4	16584.5	528	NOT VALID	-				
MECO4	16632.3	637	438	2.25				

(1) TEMPERATURE AND PRESSURE ARE FOR LARGE HELIUM BOTTLE. THE TABULATED MASS REFLECTS DIFFERENT TEMPERATURE LEVELS IN THE LARGE AND SMALL BOTTLES.

APPLICATION TO TC-5 MISSION

- TC-2 DEMONSTRATED THAT FLIGHT HELIUM USAGES AND HELIUM BOTTLE BLOWDOWN PRESSURES DURING PROPELLANT TANK PRESSURIZATIONS CAN BE ACCURATELY SIMULATED WITH EXISTING COMPUTER PROGRAMS.

- HELIUM MONITOR DEVELOPMENT FOR TC-5 MISSION WAS DUE TO:

  - THE NEED TO GUARANTEE 500 PSIA MINIMUM HELIUM BOTTLE PRESSURE THROUGH MES6, AND THIS CAN ONLY BE ACHIEVED WITH ACCURATE DETERMINATION OF HELIUM PRESSURANT USAGES,

  - THE KNOWLEDGE THAT NORMALIZED CURVES OF HELIUM MASS FLOW AND HELIUM BOTTLE PRESSURE ARE APPLICABLE FOR A WIDE RANGE OF MISSION CONDITIONS,

  - THE KNOWLEDGE THAT ACCURATE SOLENOID VALVE ON-TIMES COUPLED WITH CURVE FITS OF NORMALIZED CURVES WILL ALLOW HELIUM CONSUMPTION TO BE MONITORED THROUGHOUT THE TC-5 MISSION.

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ORIGINAL PAGE IS OF POOR QUALITY

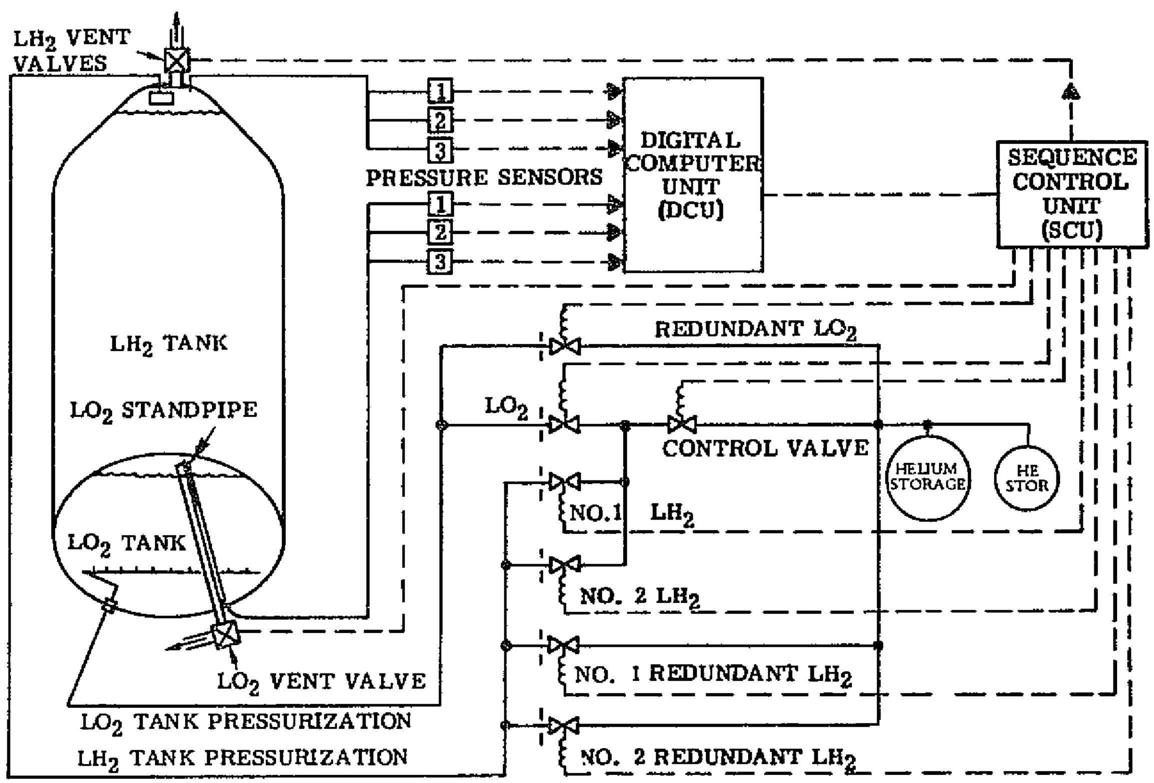
TC-2 POST HELIOS EXPERIMENT DATA REVIEW

I	INTRODUCTION	HUBER
II	PROPELLANT BEHAVIOR	MERINO
III	HELIUM USAGE	MERINO
IV	PROPELLANT TANK PRESSURIZATION	MERINO
V	PROPELLANT TANK THERMODYNAMICS	MERINO
VI	COMPONENT HEATING & THERMAL CONTROL	CHRISTENSEN
VII	MAIN ENGINE SYSTEM	HUBER
VIII	H_2O_2 CONSUMPTION	HUBER
IX	BOOST PUMP POST-MECO PERFORMANCE	HUBER/MERINO
X	OVERVIEW OF OTHER SYSTEMS	HUBER

PROPELLANT TANK PRESSURIZATION

- LO_2 TANK PRESSURIZATION AND PREFLIGHT PREDICTIONS
- LH_2 TANK PRESSURIZATION AND PREFLIGHT PREDICTIONS
- LO_2 SUMP CONDITIONS FOR MAIN ENGINE START
- LH_2 SUMP CONDITIONS FOR MAIN ENGINE START

COMPUTER CONTROLLED VENT AND PRESSURIZATION SYSTEM (CCVAPS)



PRE-MES1 LO2 TANK PRESSURIZATION

- PRE-FLIGHT PREDICTIONS BASED UPON TC-1 FLIGHT DATA
- PRESSURE RISE RATES, DECAY RATES, AND RECYCLES WERE THE SAME AS FOR TC-1, TC-3 AND TC-4 FLIGHTS.
- HELIUM USAGES WERE THE SAME AS FOR TC-1, TC-3 AND TC-4 FLIGHTS
- INITIAL PRESSURE = 32.15 PSIA
- CLOSING PRESSURE = 39.12 PSIA (PHASE 4)
  = 39.91 PSIA (PHASE 5)
- RE-OPEN CYCLES = 38.92 PSIA (PHASE 4)
  = 39.71 PSIA (PHASE 5)

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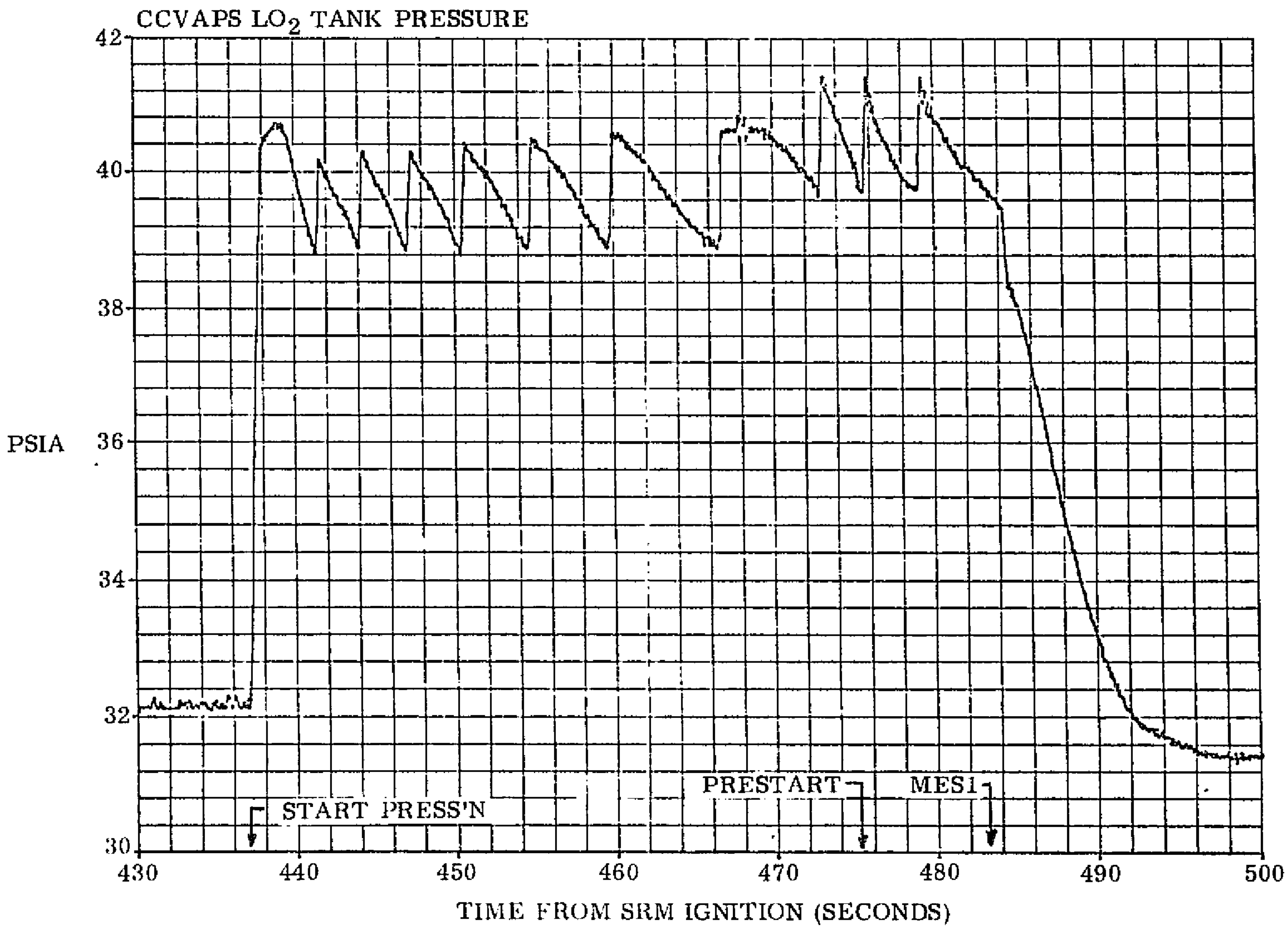
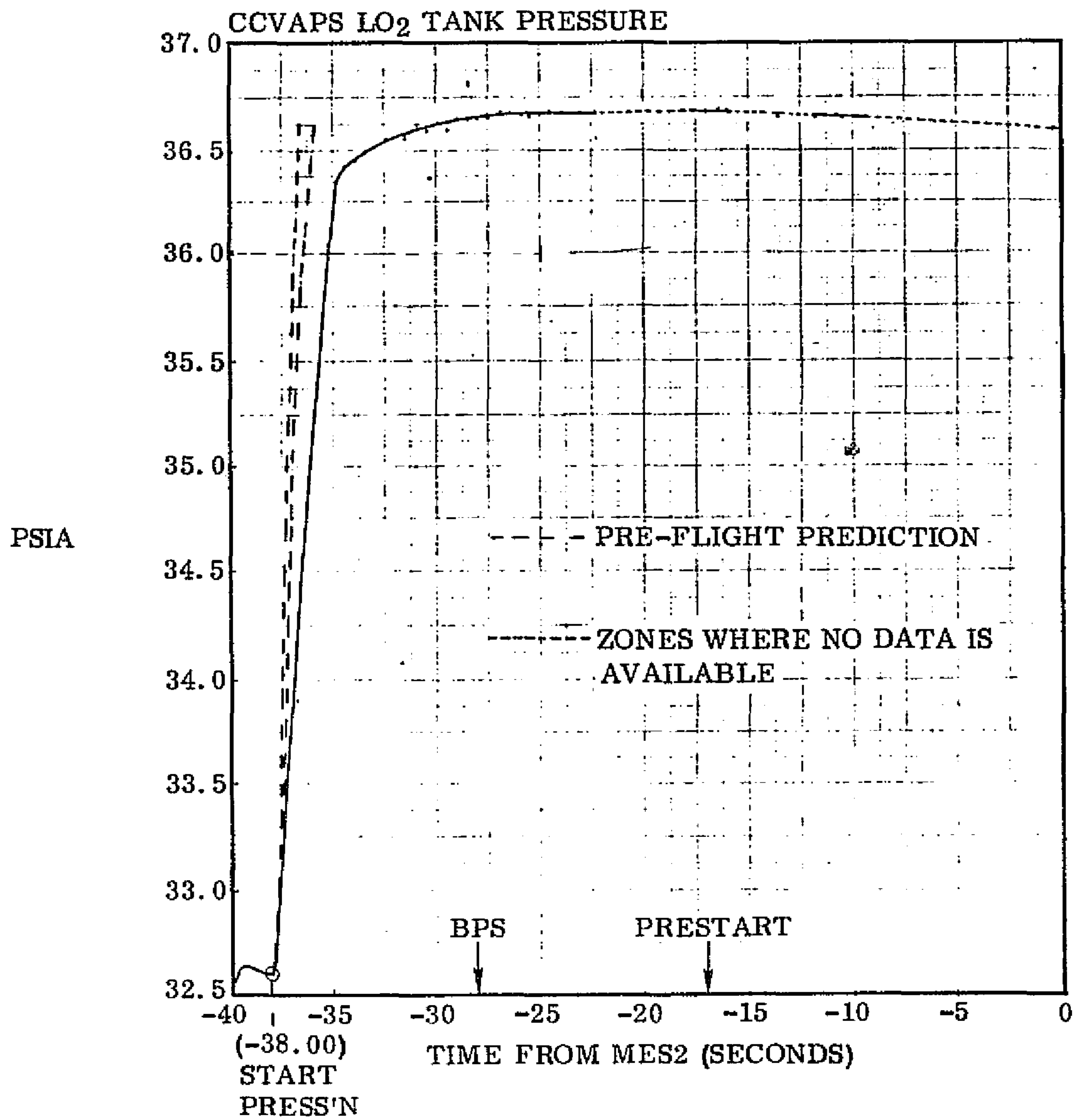
LO_2 TANK MES1 PRESSURIZATION



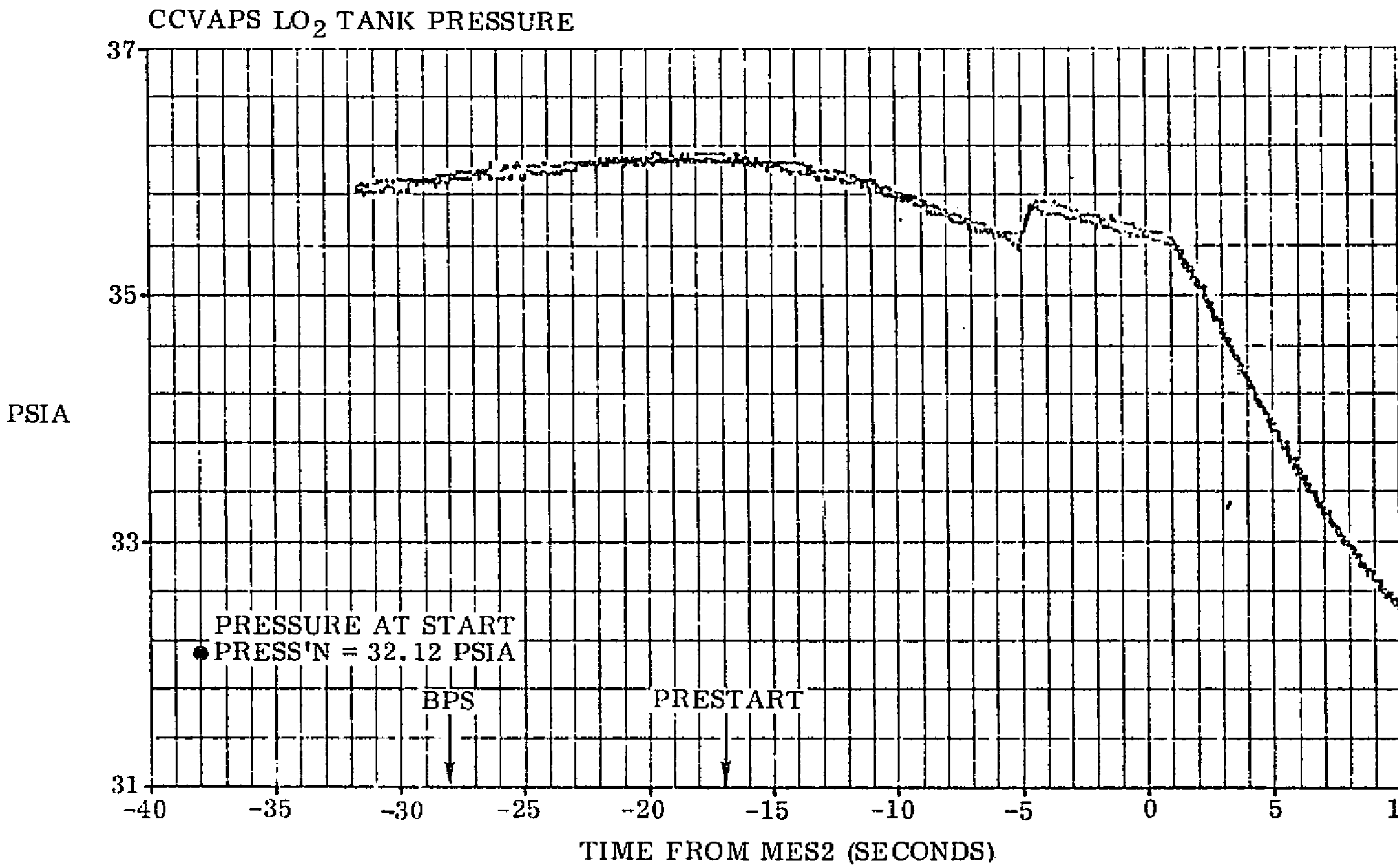
PRE-MES2 LO2 TANK PRESSURIZATION

- PRE-FLIGHT PREDICTIONS BASED UPON B2 TEST DATA
- INITIAL PRESSURE = 32.61 PSIA
- CLOSING PRESSURE = 36.11 PSIA
- RE-OPEN CYCLES = 35.91 PSIA
- PRESSURE RISE RATES LESS THAN MINIMUM PREDICTED. DIFFERENCE MAY BE DUE TO GREATER LO2 EVAPORATION IN ONE-G (B2 TESTS) THAN IN LOW-G.
- NO INFORMATION ON RE-CYCLES DUE TO LOSS OF TELEMETRY.
- A 0.33 PSID PRESSURE INCREASE OCCURRED FOLLOWING RAMP PRESSURIZATION.
- IT IS BELIEVED THAT PRESSURE INCREASE IS DUE TO LO2 EVAPORATION INTO HELIUM BUBBLES THAT RESIDE BENEATH LIQUID SURFACE.
- TC-3 DATA SUGGESTS THAT ONE RECYCLE MAY HAVE OCCURRED PRIOR TO MES2.

LO_2 TANK MES2 PRESSURIZATION



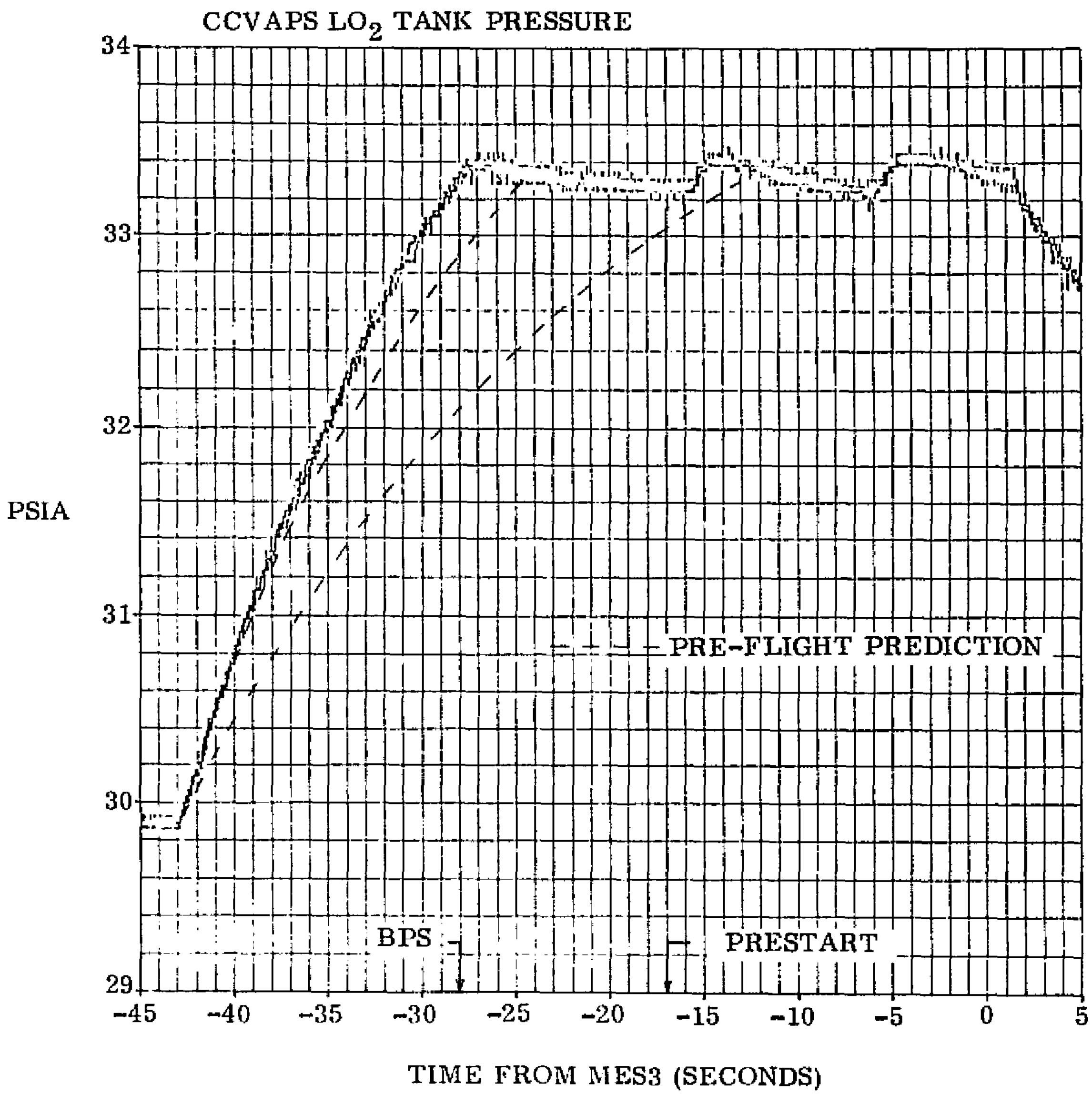
TC-3 LO_2 TANK MES2 PRESSURIZATION



PRE-MES3 LO2 TANK PRESSURIZATION

- PRE-FLIGHT PREDICTIONS BASED UPON THEORETICAL MODEL OF HELIUM JET FLOW BENEATH LIQUID SURFACE
- INITIAL PRESSURE = 29.89 PSIA
- CLOSING PRESSURE = 33.39 PSIA
- RE-OPEN CYCLES = 33.19 PSIA
- PRESSURE RISE RATES GREATER THAN MAXIMUM PREDICTED.
- HAVE NOT OBTAINED GOOD HELIUM USAGE AND PRESSURE RISE MATCH WITH MODEL.
- DISCREPANCY OF 24% BETWEEN ACTUAL AND PREDICTED HELIUM USAGE MAY BE DUE TO SUBSTANTIAL CHILLING OF LIQUID ABOVE BUBBLER RESULTING FROM LO2 EVAPORATION INTO HELIUM.
- THERE IS NO PRESSURE INCREASE FOLLOWING TERMINATION OF HELIUM FLOW BECAUSE THERE IS NO HELIUM BENEATH LIQUID SURFACE TO STIMULATE LO2 EVAPORATION.

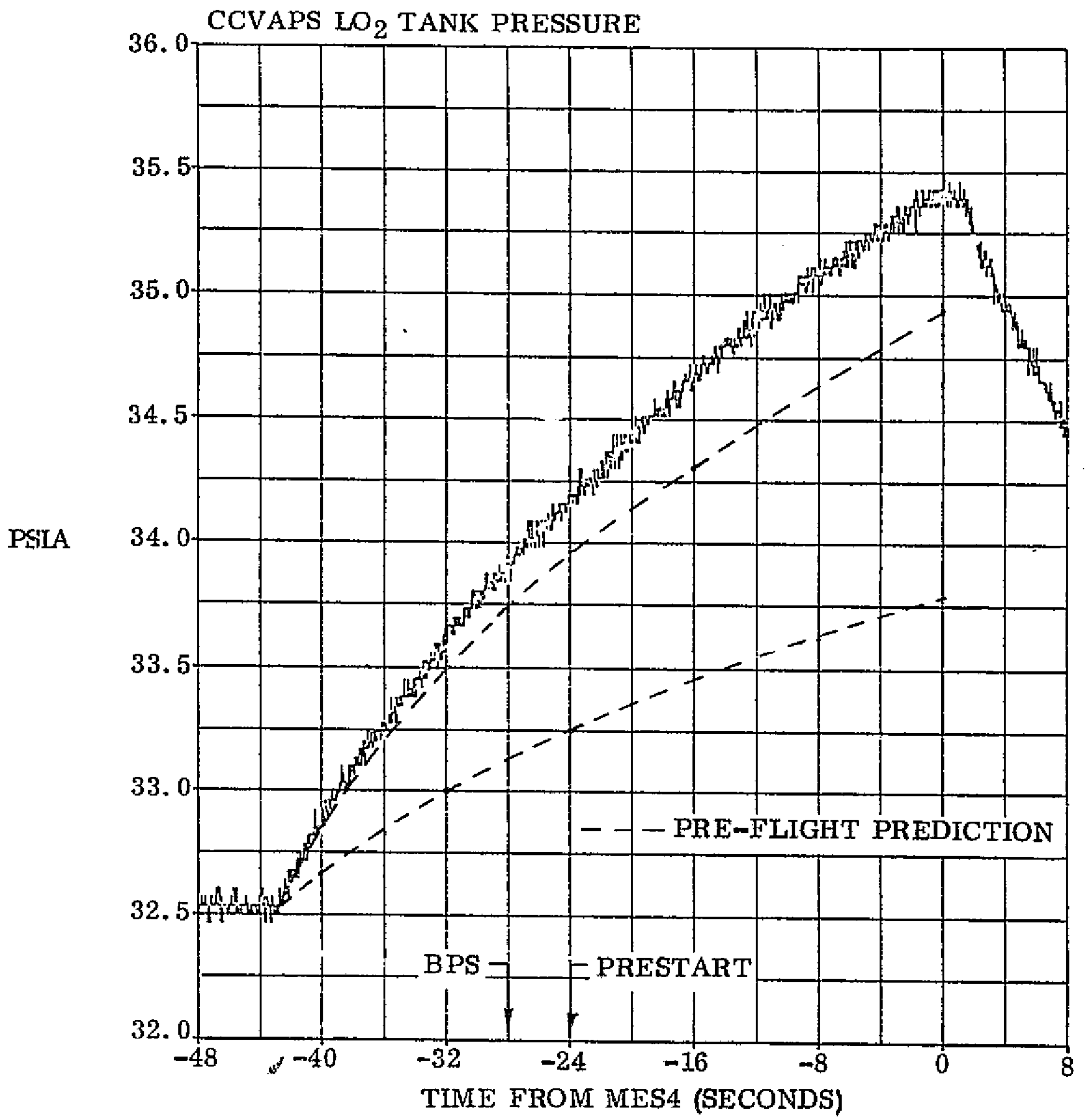
LO_2 TANK MES3 PRESSURIZATION



PRE-MES4 LO2 TANK PRESSURIZATION

- PRE-FLIGHT PREDICTIONS BASED UPON THEORETICAL MODEL OF HELIUM JET FLOW BENEATH LIQUID SURFACE
- INITIAL PRESSURE = 32.50 PSIA
- CLOSING PRESSURE = 36.00 PSIA
- RE-OPEN CYCLES = 35.80 PSIA
- PRESSURE RISE RATES GREATER THAN MAXIMUM PREDICTED
- POST FLIGHT SIMULATIONS HAVE NOT RESULTED IN GOOD MATCH WITH HELIUM USAGE AND PRESSURE RISE RATE
- DISCREPANCY OF 24% BETWEEN ACTUAL AND PREDICTED USAGE MAY BE DUE TO SUBSTANTIAL CHILLING OF LIQUID ABOVE BUBBLER RESULTING FROM LO2 EVAPORATION INTO HELIUM
- THERE IS NO PRESSURE INCREASE FOLLOWING TERMINATION OF HELIUM FLOW BECAUSE THERE IS NO HELIUM BENEATH LIQUID SURFACE TO STIMULATE LO2 EVAPORATION.

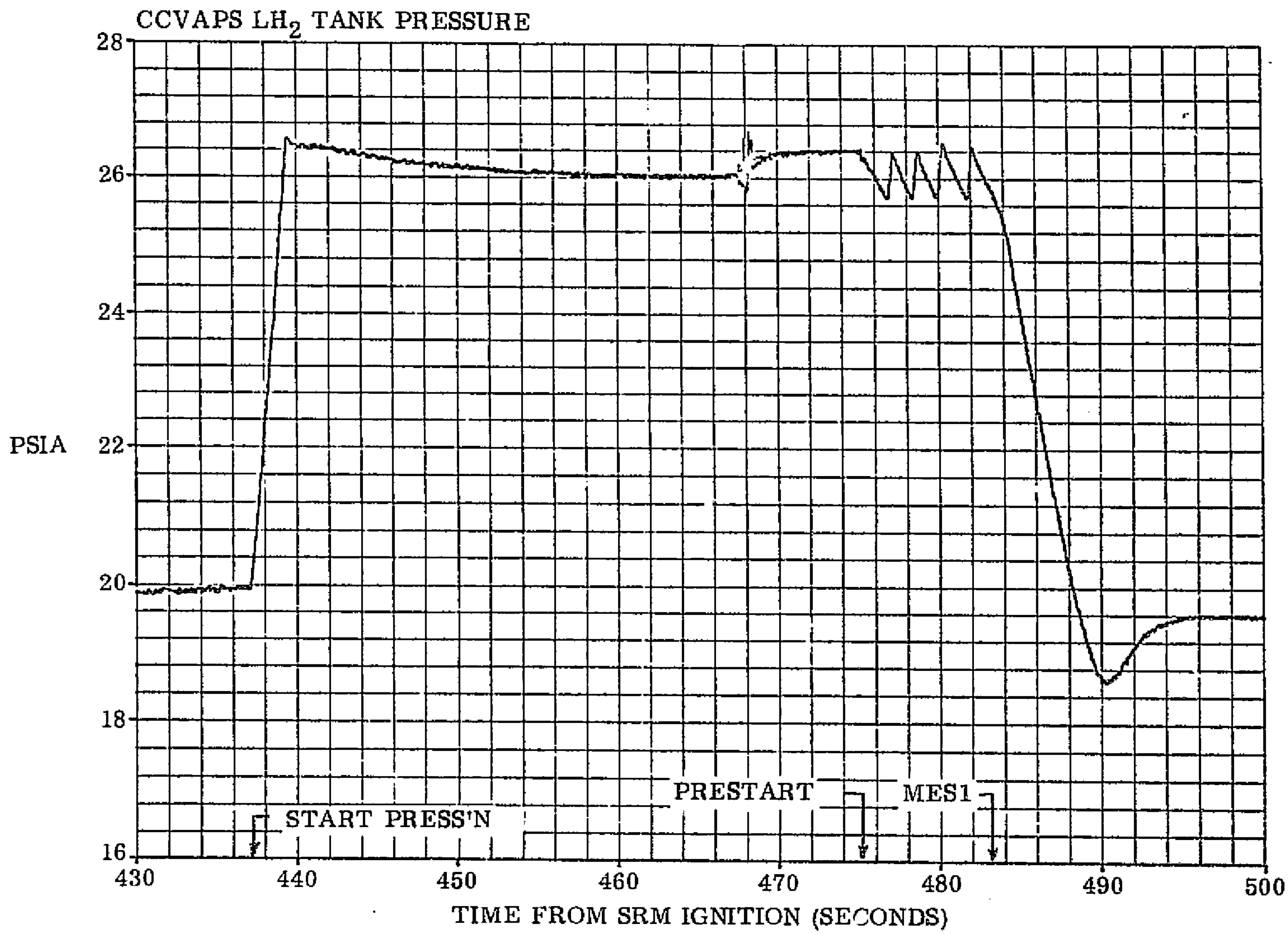
LO_2 TANK MES4 PRESSURIZATION



PRE-MES1 LH2 TANK PRESSURIZATION

- PRE-FLIGHT PREDICTIONS BASED UPON TC-1 FLIGHT DATA
- PRESSURE RISE RATES, DECAY RATES, AND RECYCLES WERE THE SAME AS FOR TC-1, TC-3 AND TC-4 FLIGHTS
- HELIUM USAGES WERE THE SAME AS FOR TC-1, TC-3 AND TC-4 FLIGHTS
- INITIAL PRESSURE = 19.92 PSIA
- CLOSING PRESSURE = 25.92 PSIA (PHASES 4 AND 5)
- REOPEN CYCLES = 25.72 PSIA (PHASES 4 AND 5)

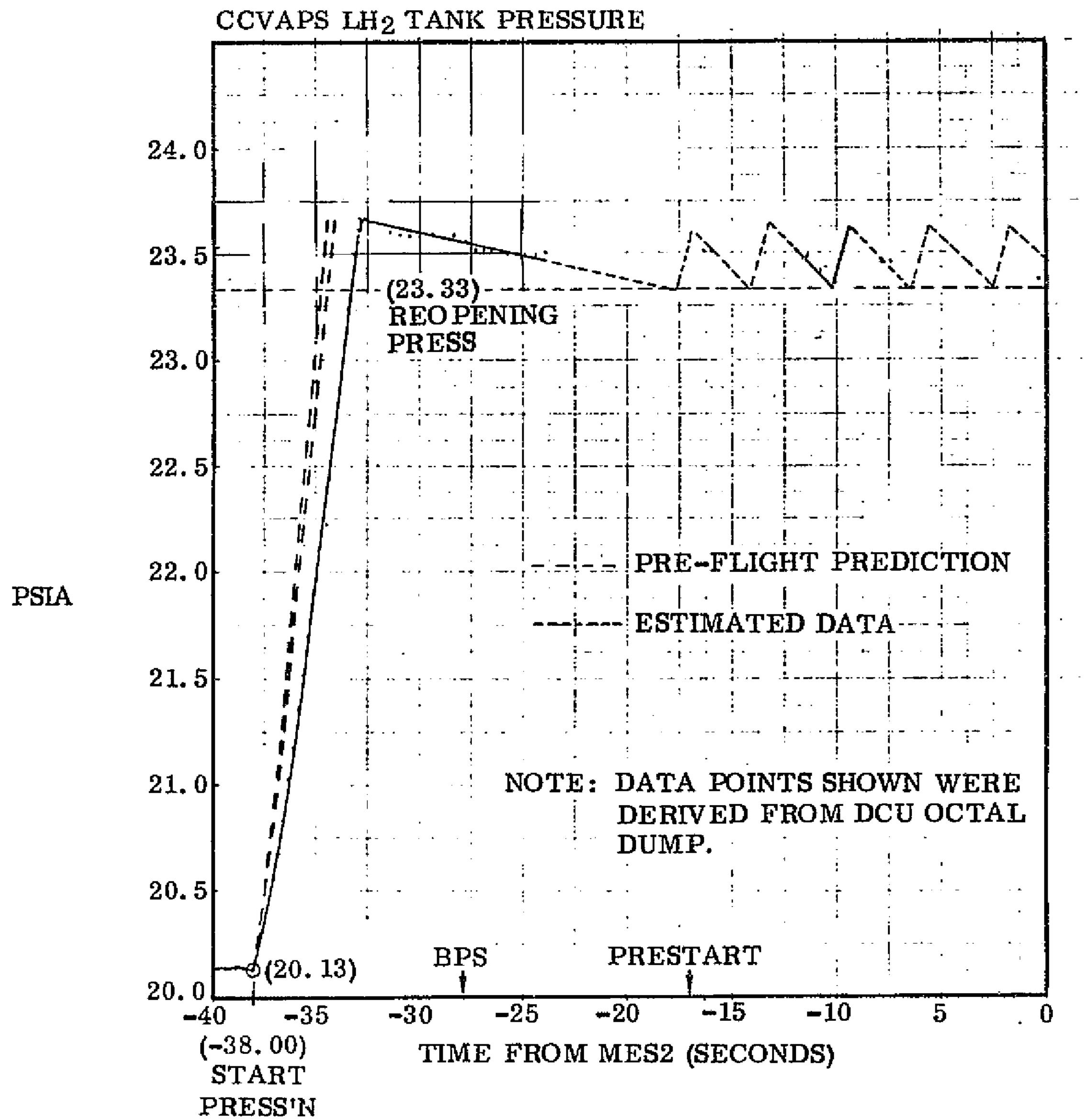
LH_2 TANK MES1 PRESSURIZATION



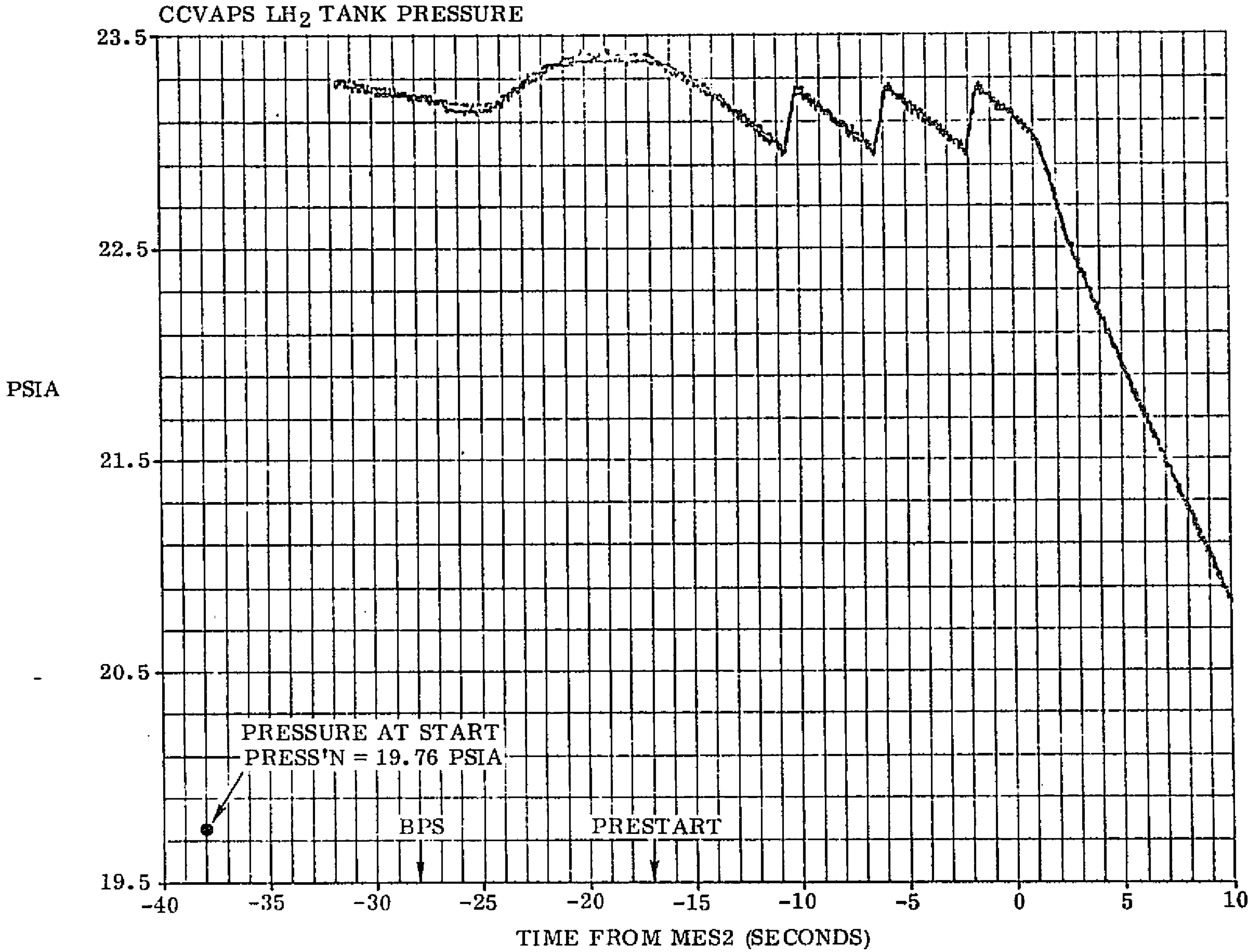
PRE-MES2 LH2 TANK PRESSURIZATION

- PRE-FLIGHT PREDICTIONS BASED UPON B2 TEST DATA
- INITIAL PRESSURE = 20.13 PSIA
- CLOSING PRESSURE = 23.53 PSIA
- RE-OPEN CYCLES = 23.33 PSIA
- PRESSURE RISE RATES LESS THAN MINIMUM PREDICTED. ENERGY DISSIPATOR DIRECTED HELIUM AT LH2 SURFACE FOR B2 TESTS. THE TC-2 ENERGY DISSIPATOR DIRECTED HELIUM RADIALLY OUTWARD AT THE FORWARD BULKHEAD. HEAT TRANSFER TO FORWARD BULKHEAD COULD HAVE BEEN RESPONSIBLE FOR REDUCED TC-2 PRESSURE RISE RATE. THERE WAS NO CORRESPONDING HEAT LOSS TO FORWARD BULKHEAD DURING B2 TESTS.
- NO INFORMATION ON RE-CYCLES DUE TO LOSS OF TELEMETRY
- TELEMETRY LOSS DID NOT REVEAL A PRESSURE INCREASE FOLLOWING BOOST PUMP START.
  NOTE: TC-3 AND TC-4 FLIGHTS INDICATED $\approx$ 0.2 PSID INCREASE. IT IS BELIEVED THAT THE INCREASE WAS DUE TO VAPOR FLOW INTO THE TANK THROUGH THE RE-CIRCULATION LINE DURING CHILLDOWN OF THE PROPELLANT DUCTING.
- TC-3 DATA SUGGESTS THAT TWO RECYCLES MAY HAVE OCCURRED PRIOR TO MES2.

LH2 TANK MES2 PRESSURIZATION



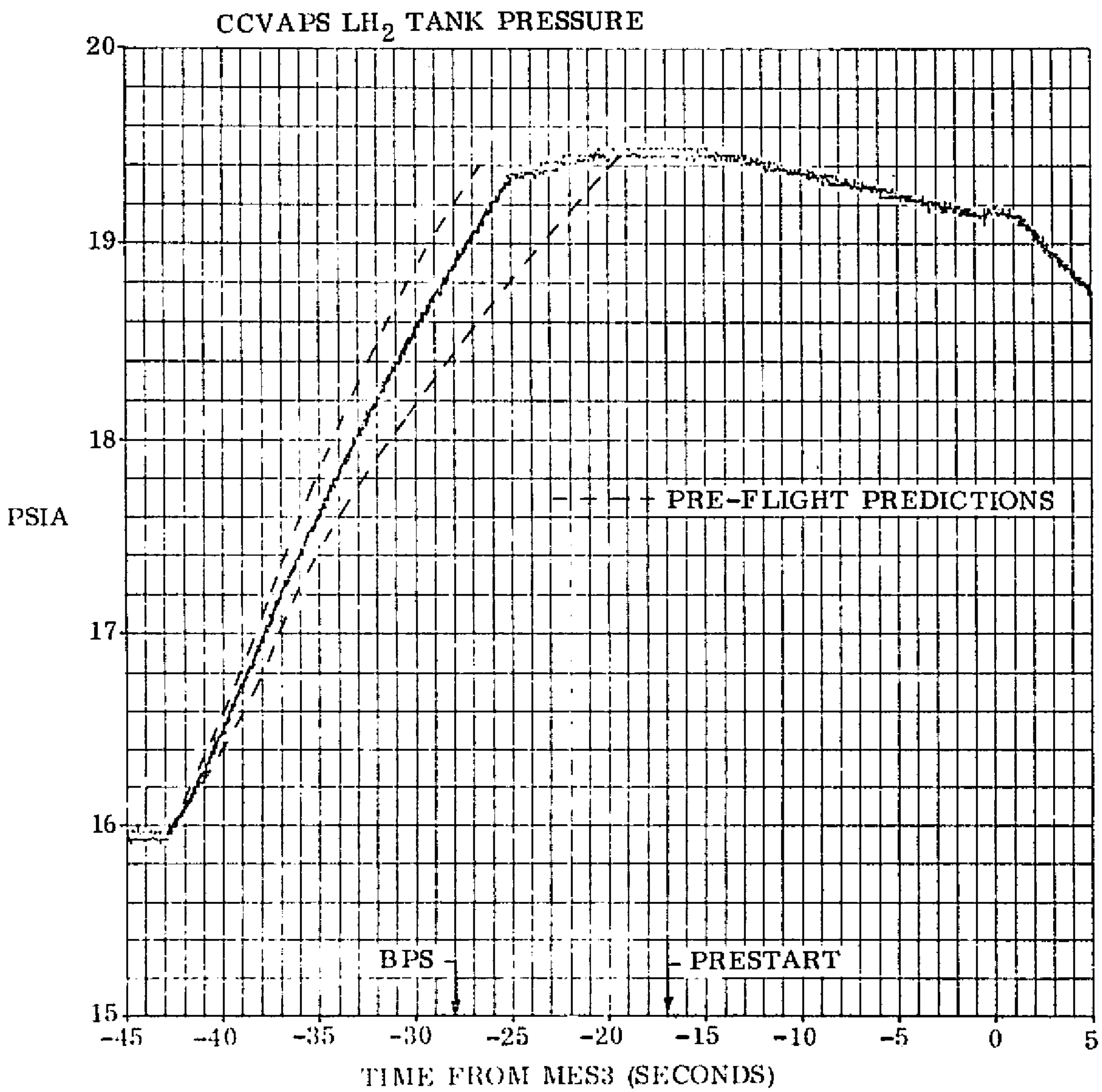
TC-3 LH_2 TANK MES2 PRESSURIZATION



PRE-MES3 LH2 TANK PRESSURIZATION

- PRE-FLIGHT PREDICTIONS BASED UPON TANK THERMODYNAMIC MODEL (PROGRAM P3995H)
- INITIAL PRESSURE = 15.93 PSIA
- CLOSING PRESSURE = 19.33 PSIA
- RE-OPEN CYCLES = 19.13 PSIA
- GOOD AGREEMENT EXISTS BETWEEN PREDICTED AND ACTUAL RAMP PRESSURE INCREASE.
- FOLLOWING BOOST PUMP START A 0.12 PSID PRESSURE INCREASE OCCURRED. THE INCREASE IS BELIEVED TO BE CAUSED BY VAPOR FLOW INTO THE TANK THROUGH THE RECIRCULATION LINE DURING CHILLDOWN OF THE PROPELLANT DUCTING.
- A VALVE RE-CYCLE OF 0.38 SECOND DURATION OCCURRED PRIOR TO MES3.

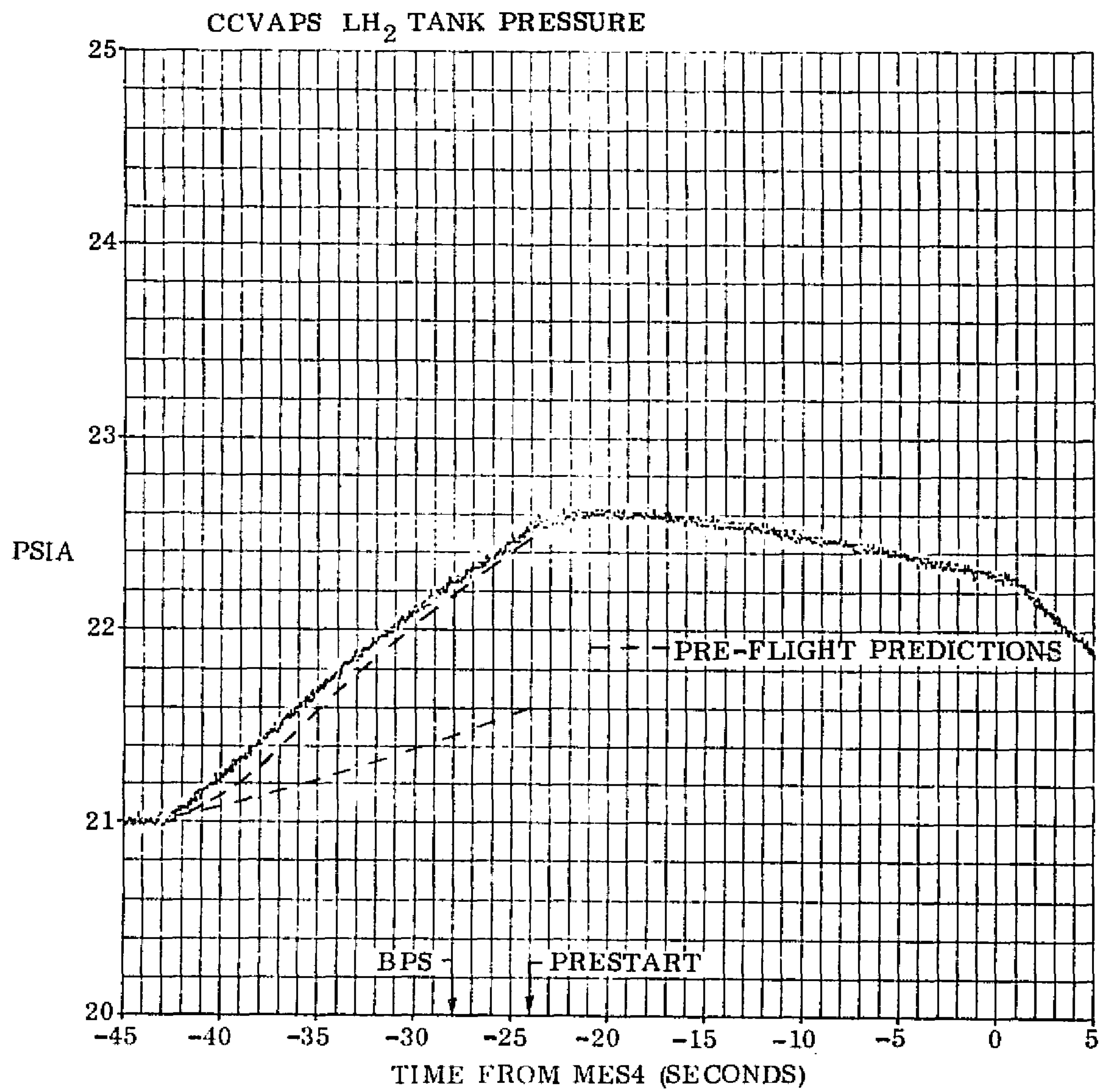
LH_2 TANK MES3 PRESSURIZATION



PRE-MES4 LH2 TANK PRESSURIZATION

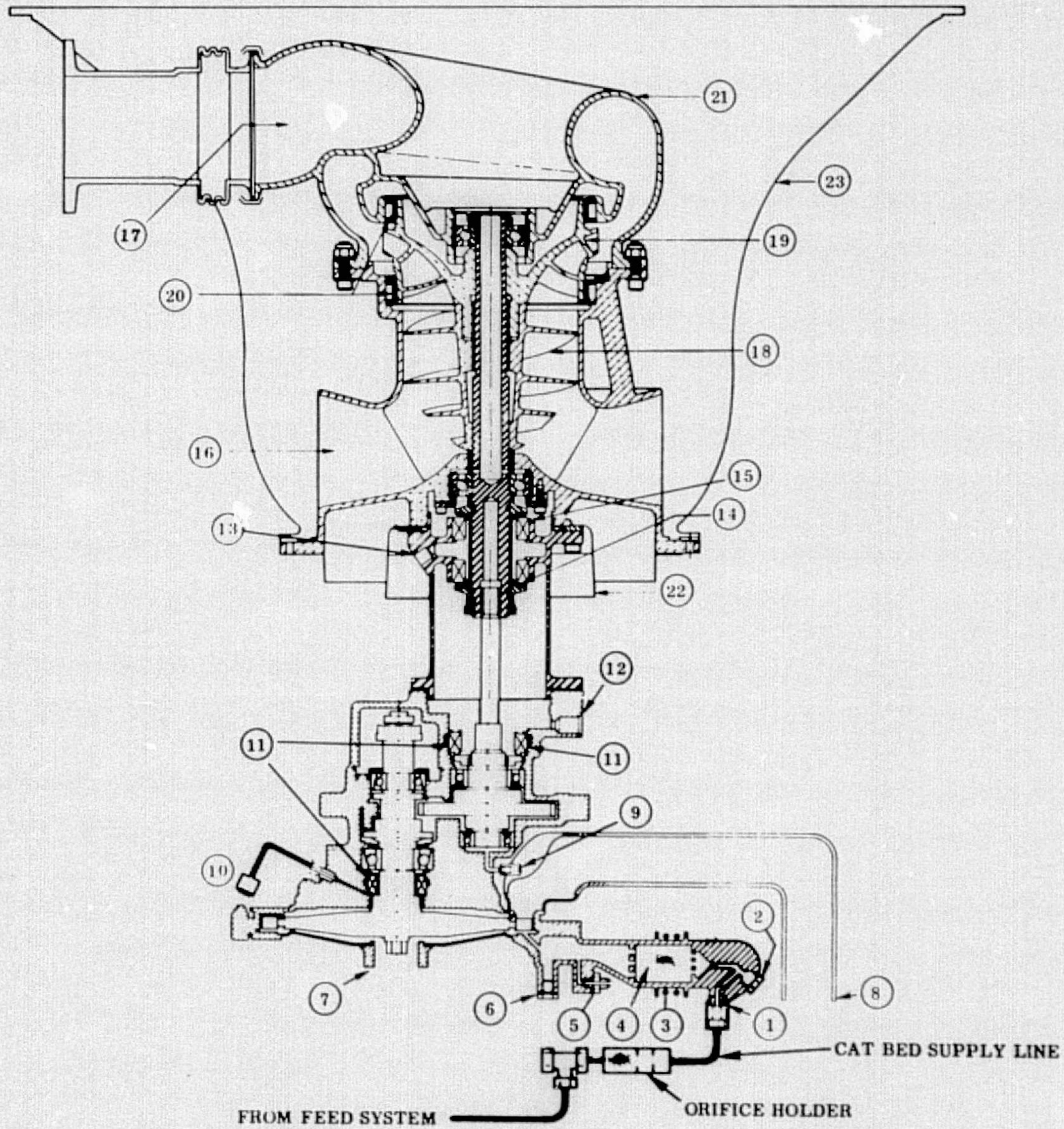
- PRE-FLIGHT PREDICTIONS BASED UPON TANK THERMODYNAMIC MODEL (PROGRAM P3995H)
- INITIAL PRESSURE = 21.01 PSIA
- CLOSING PRESSURE = 23.91 PSIA
- RE-OPEN CYCLE = 23.71 PSIA
- PRESSURE RISE SLIGHTLY GREATER THAN MAXIMUM PREDICTED.
- FOLLOWING BOOST PUMP START A 0.08 PSID PRESSURE INCREASE OCCURRED. THE INCREASE IS BELIEVED TO BE CAUSED BY VAPOR FLOW INTO THE TANK THROUGH THE RECIRCULATION LINE DURING CHILLDOWN OF THE PROPELLANT DUCTING.
- PRESSURIZATION WAS TERMINATED BY TIME (19 SECOND FLOW DURATION).

LH_2 TANK MES4 PRESSURIZATION



OXIDIZER BOOST PUMP LINE

1. CATALYST BED INLET
2. GAS GENERATOR PRESSURE
3. CATALYST BED HEATER
4. CATALYST BED
5. TURBINE INLET PRESSURE
6. TURBINE INLET TEMPERATURE
7. TURBINE ACCESS PORT
8. TURBINE EXHAUST
9. GEAR CASE VENT CHECK VALVE
10. TURBINE SEAL VENT
11. TURBINE DYNAMIC SEAL
12. SECONDARY SEAL VENT
13. PRIMARY SEAL VENT
14. SECONDARY SEAL
15. PRIMARY SEAL
16. INLET
17. DISCHARGE
18. INDUCER
19. IMPELLER
20. LABYRINTH SEAL
21. VOLUTE
22. INSULATION
23. SUMP



LO_2 SUMP TEMPERATURES

GENERAL DYNAMICS
Convair Division
31 Oct 75

PRE-MES1

- LO_2 INITIALLY SATURATED AT 31.60 PSIA
- NO VAPOR IN SUMP PRIOR TO BPS
- TEMPERATURE INCREASE BEGINS AT BPS + 8 SECONDS
- $0.77^{\circ}R$ TEMPERATURE INCREASE BY MES1 DUE TO BEARING COOLANT AND VOLUTE FLOWS

PRE-MES3

- LO_2 INITIALLY SATURATED AT TANK PRESSURE (29.89 PSIA)
- $1.56^{\circ}R$ TEMPERATURE RISE PRIOR TO BPS INDICATES $\approx$ 50% VAPOR BY VOLUME INITIALLY IN SUMP
- WARM FLUID BEGINS FLOW OUT OF SUMP AT BPS + 1.5 SECONDS
- TEMPERATURE INCREASE BEGINNING AT BPS + 7 SECONDS IS CAUSED BY VOLUTE AND BEARING COOLANT FLOWS
- TEMPERATURE DECAY AFTER MES INDIC. LIQUID BULK IS SUBCOOLED BY $\approx$ 1.0 PSID BELOW INITIAL TANK PRESSURE

LO_2 SUMP TEMPERATURES (Contd)

PRE-MES4

- LO2 INITIALLY SATURATED AT TANK PRESSURE (32.50 PSIA)
- $0.77^{\circ}R$ TEMPERATURE RISE PRIOR TO BPS INDICATES $\approx$ 33% VAPOR BY VOLUME INITIALLY IN SUMP
- WARM FLUID BEGINS FLOW OUT OF SUMP AT BPS + 1.5 SECONDS
- TEMPERATURE INCREASE BEGINNING AT BPS + 7 SECONDS IS CAUSED BY VOLUTE AND BEARING COOLANT FLOWS
- TEMPERATURE DECAY AFTER MES INDICATES LIQUID BULK IS SUBCOOLED BY $\approx$ 1.4 PSID BELOW INITIAL TANK PRESSURE

GENERAL DYNAMICS
Convair Division
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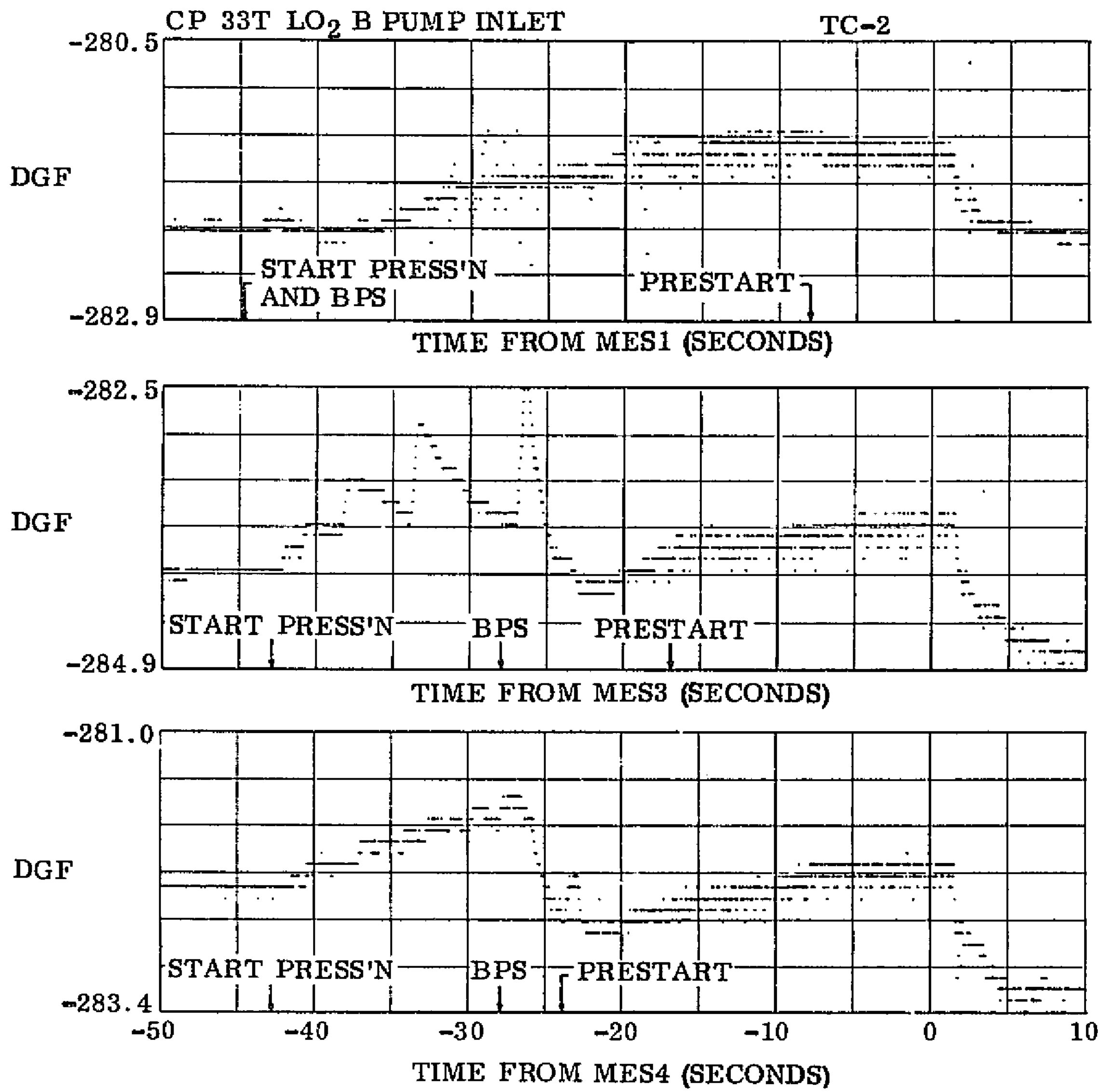
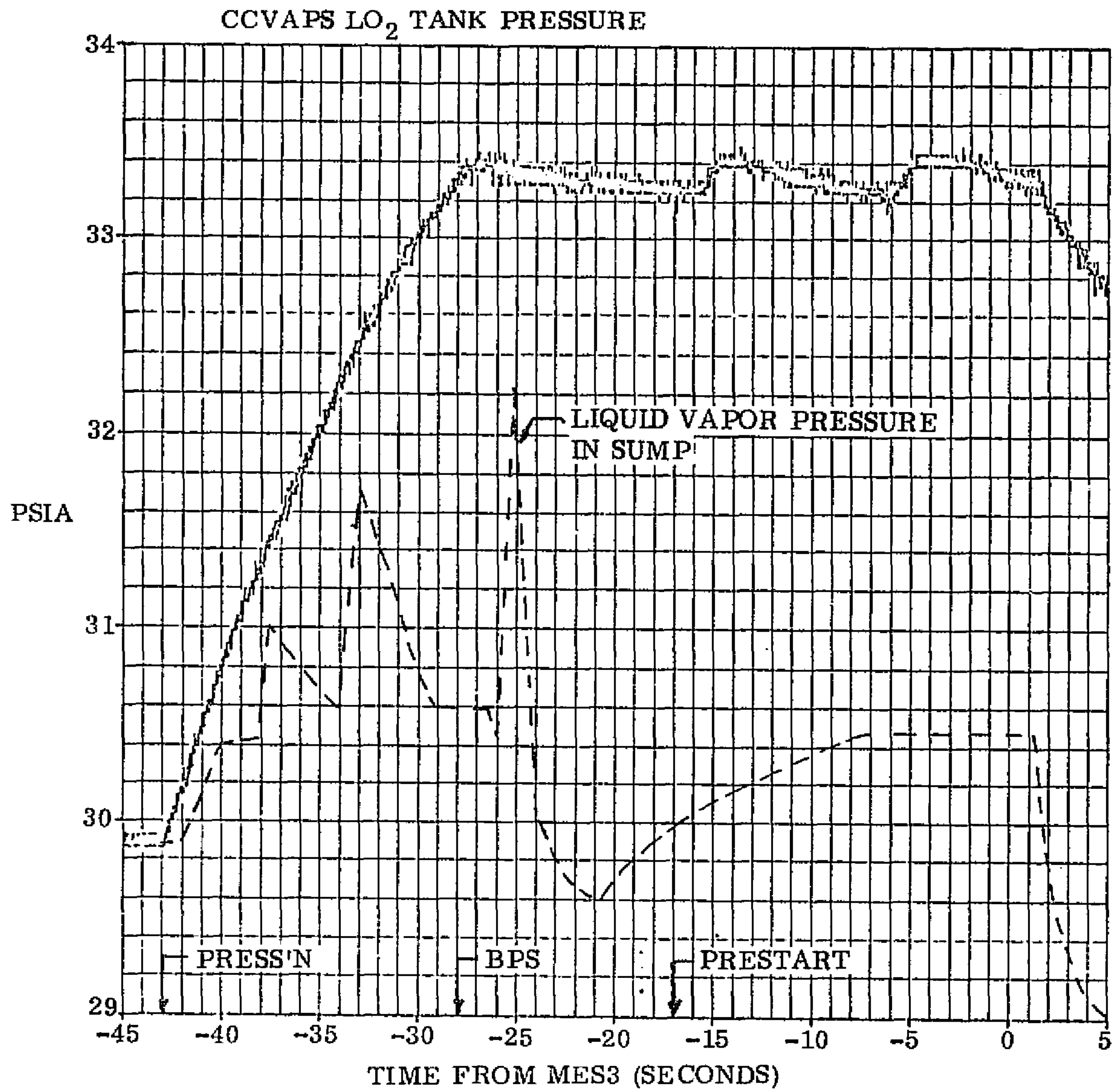
LO_2 SUMP TEMPERATURES FOR MAIN ENGINE START



PRE-MES3 LO2 BOOST PUMP NPSP CONDITIONS

- LO2 INITIALLY SATURATED AT TANK PRESSURE
- NPSP = 2.7 PSID AT BPS
- NPSP = 1.1 PSID AT BPS + 3 SECONDS - MINIMUM NPSP CONDITION
- NPSP = 3.3 PSID AT BPS + 4 SECONDS
  WARM LO2 IS BEING PUMPED FROM SUMP AND REPLACED BY COOLER LIQUID
- NPSP = 3.7 PSID AT BPS + 7 SECONDS
  BEYOND THIS TIME VOLUTE AND BEARING COOLANT FLOW BEGIN TO WARM LO2
- NPSP = 3.3 PSID AT PRESTART
- NPSP = 2.9 PSID AT MES3
- NPSP = 3.8 PSID AT MES3 + 5 SECONDS
  COLD LIQUID IS BEING PUMPED OVERBOARD.

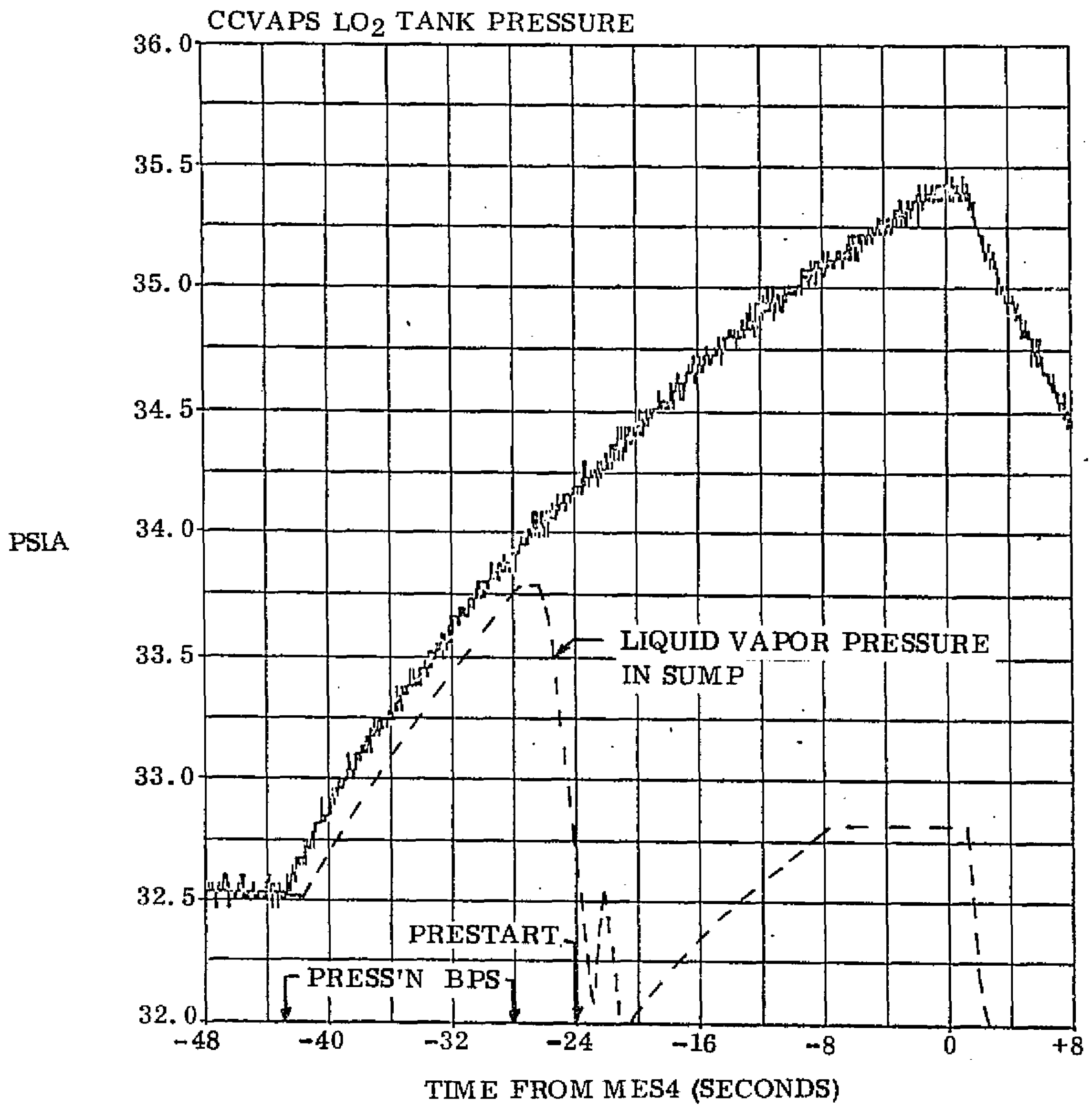
LO_2 BOOST PUMP NPSP FOR MES3



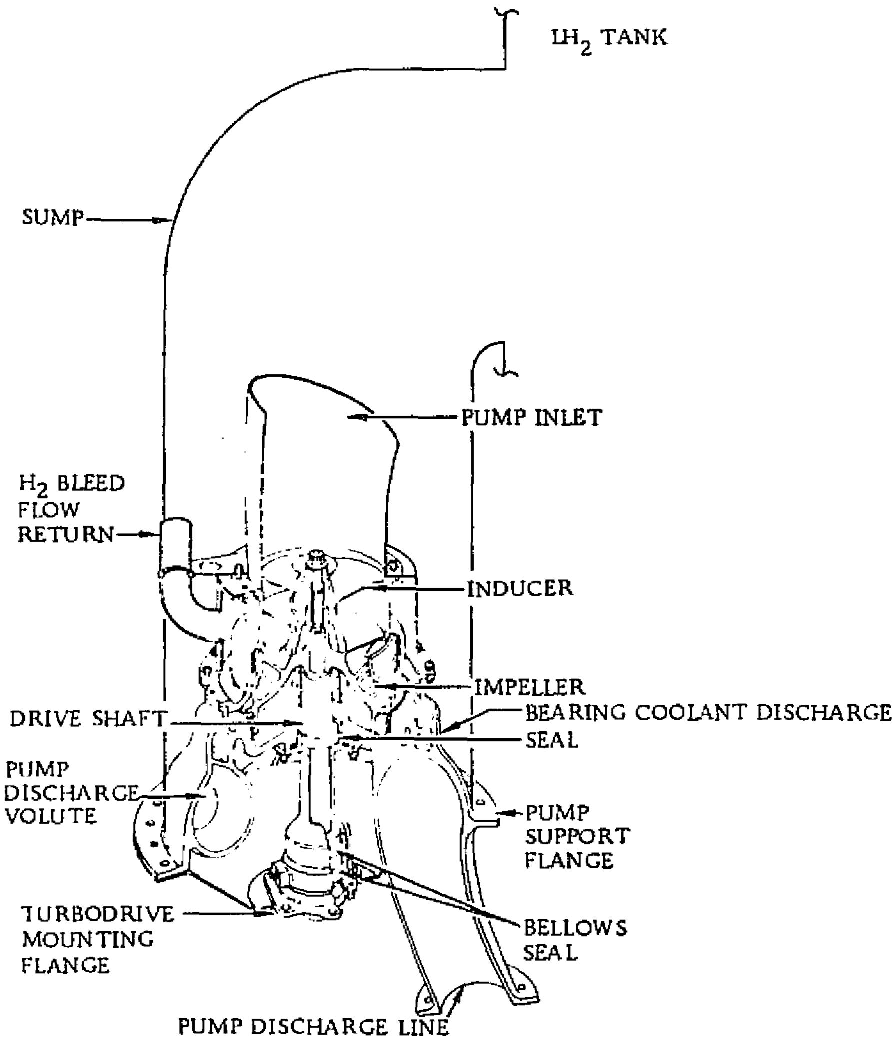
PRE-MES4 LO2 BOOST PUMP NPSP CONDITIONS

- LO2 INITIALLY SATURATED AT TANK PRESSURE
- NPSP = 0.1 PSID AT BPS
  MINIMUM NPSP CONDITION
- NPSP = 1.5 PSID AT BPS + 4 SECONDS (PRESTART)
  WARM LO2 IS BEING PUMPED FROM SUMP AND REPLACED BY COOLER LIQUID
- NPSP = 2.4 PSID AT BPS + 7 SECONDS
  BEYOND THIS TIME VOLUTE AND BEARING COOLANT FLOW BEGINS TO WARM LO2
- NPSP = 2.6 PSID AT MES4
- NPSP = 3.5 PSID AT MES4 + 10 SECONDS
  COLD LIQUID IS BEING PUMPED OVERBOARD

LO_2 BOOST PUMP NPSP FOR MES4



FUEL BOOST PUMP UNIT



LH_2 SUMP TEMPERATURES

PRE-MES1

- LH2 INITIALLY SATURATED AT 20.7 PSIA
- 0.09 $^{\circ}$R TEMPERATURE INCREASE INDICATES ≈ 5% VAPOR BY VOLUME INITIALLY IN SUMP
- 1.11 $^{\circ}$R TEMPERATURE INCREASE BY PRESTART DUE TO BEARING COOLANT FLOW
- TEMPERATURE DECAY AFTER MES INDICATES LIQUID BULK IS SUBCOOLED BY ≈ 0.6 PSID BELOW INITIAL TANK PRESSURE

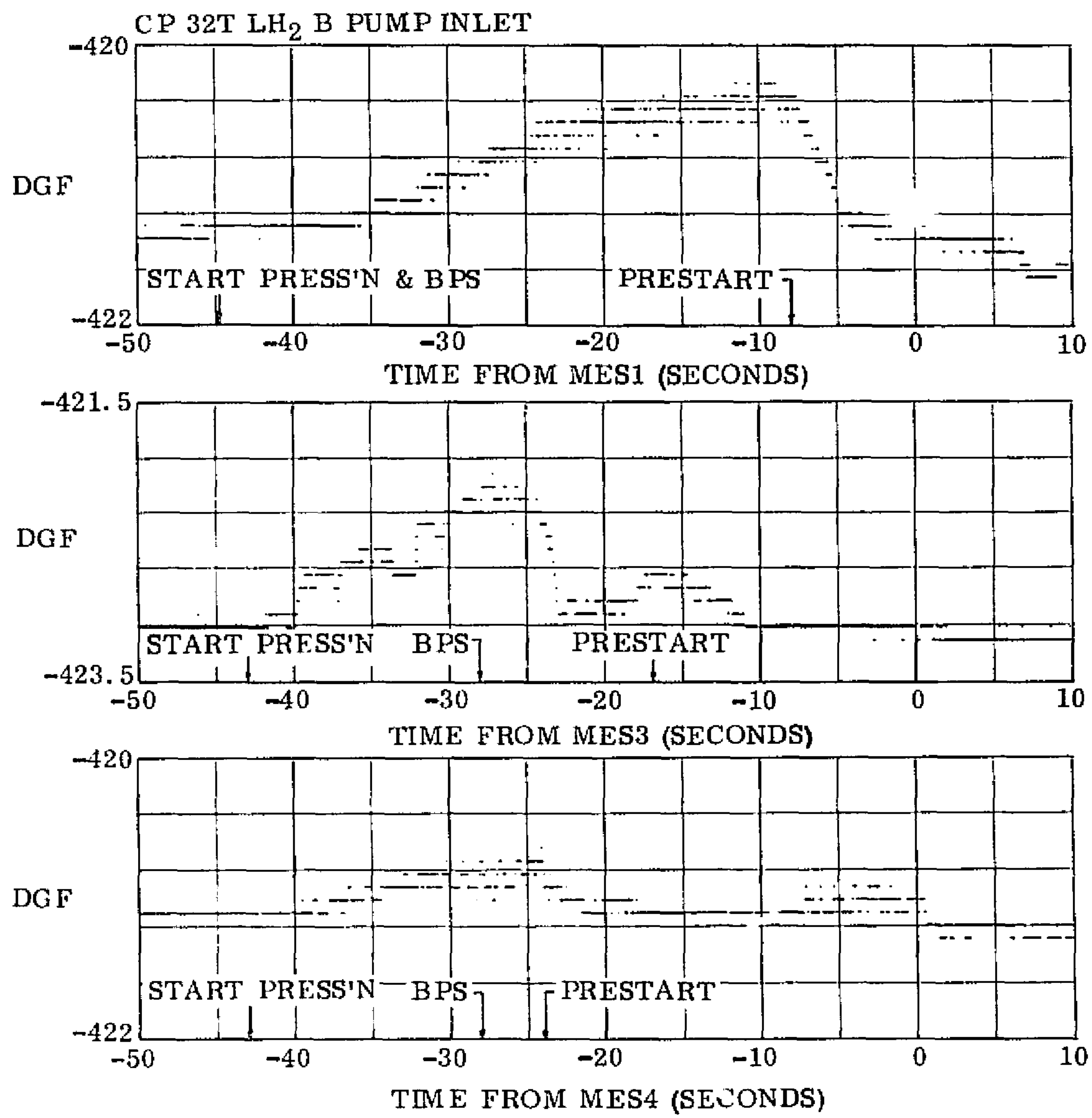
PRE-MES3

- LH2 INITIALLY SATURATED AT TANK PRESSURE (15.93 PSIA)
- 1.02 $^{\circ}$R TEMPERATURE RISE PRIOR TO BPS INDICATES ≈ 43% VAPOR BY VOLUME INITIALLY IN SUMP
- WARM FLUID BEGINS FLOW OUT OF SUMP BY BPS + 4 SECONDS
- TEMPERATURE DECAY AFTER MES INDICATES LIQUID BULK IS SUBCOOLED BY ≈ 0.22 PSID BELOW INITIAL TANK PRESSURE

PRE-MES4

- LH2 INITIALLY SATURATED AT TANK PRESSURE (21.01 PSIA)
- 0.37 $^{\circ}$R TEMPERATURE RISE PRIOR TO BPS INDICATES ≈ 18% VAPOR BY VOLUME INITIALLY IN SUMP
- WARM FLUID BEGINS FLOW OUT OF SUMP BY BPS + 4 SECONDS
- TEMPERATURE DECAY AFTER MES INDICATES LIQUID BULK IS SUBCOOLED BY ≈ 0.4 PSID BELOW INITIAL TANK PRESSURE

LH_2 SUMP TEMPERATURES FOR MAIN ENGINE START

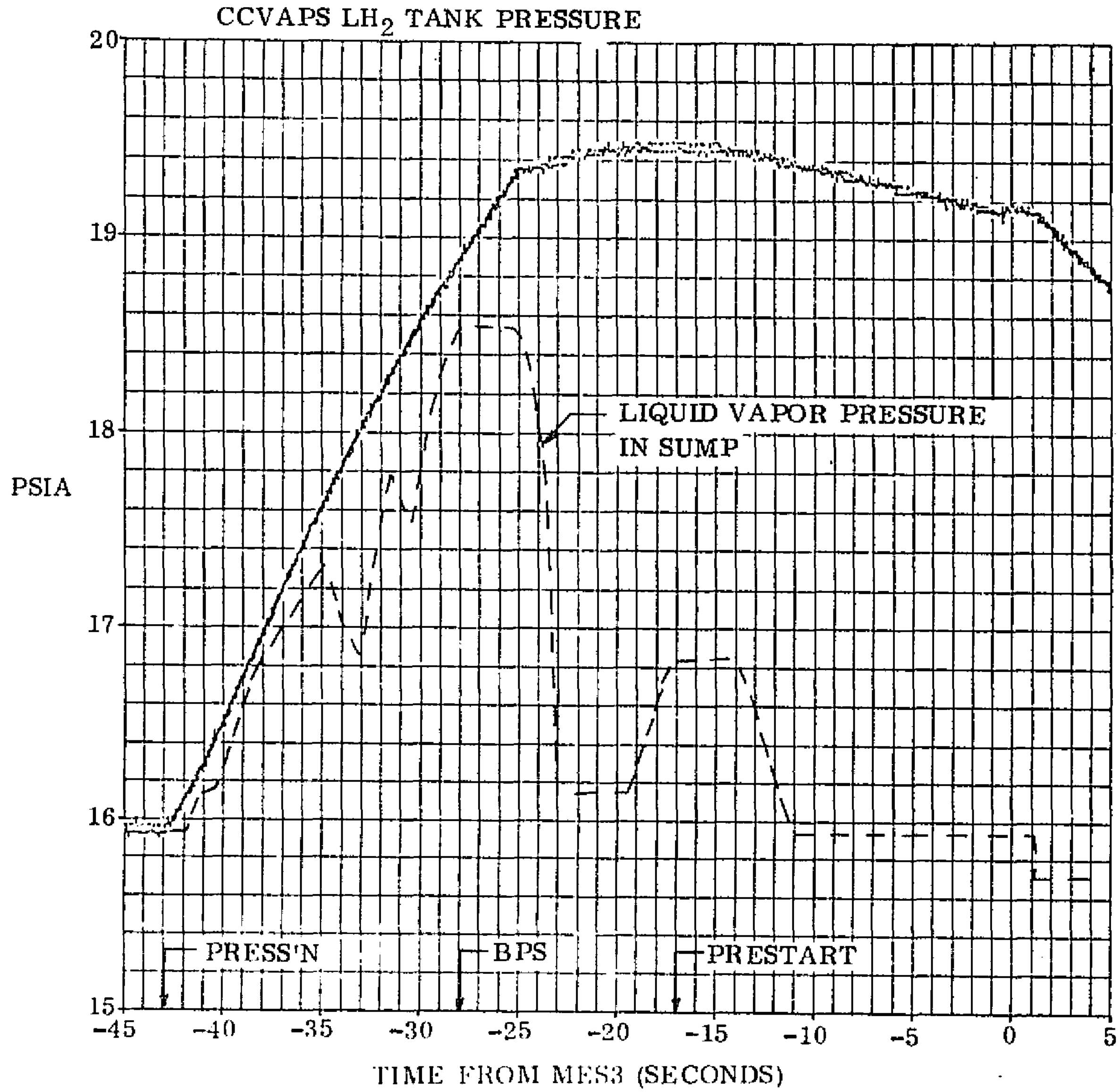


PRE-MES3 LH2 BOOST PUMP NPSP CONDITIONS

- LH2 INITIALLY SATURATED AT TANK PRESSURE
- NPSP = 0.35 PSID AT BPS
  MINIMUM NPSP CONDITION
- NPSP = 3.2 PSID AT BPS + 5 SECONDS
  WARM LH2 IS BEING PUMPED FROM SUMP AND REPLACED BY COOLER LIQUID
- NPSP = 2.7 PSID AT BPS + 11 SECONDS (PRESTART)
- NPSP = 3.2 PSID AT MES3
- NPSP = 3.1 PSID AT MES3 + 5 SECONDS

GENERAL DYNAMICS
Convair Division
31 Oct 75

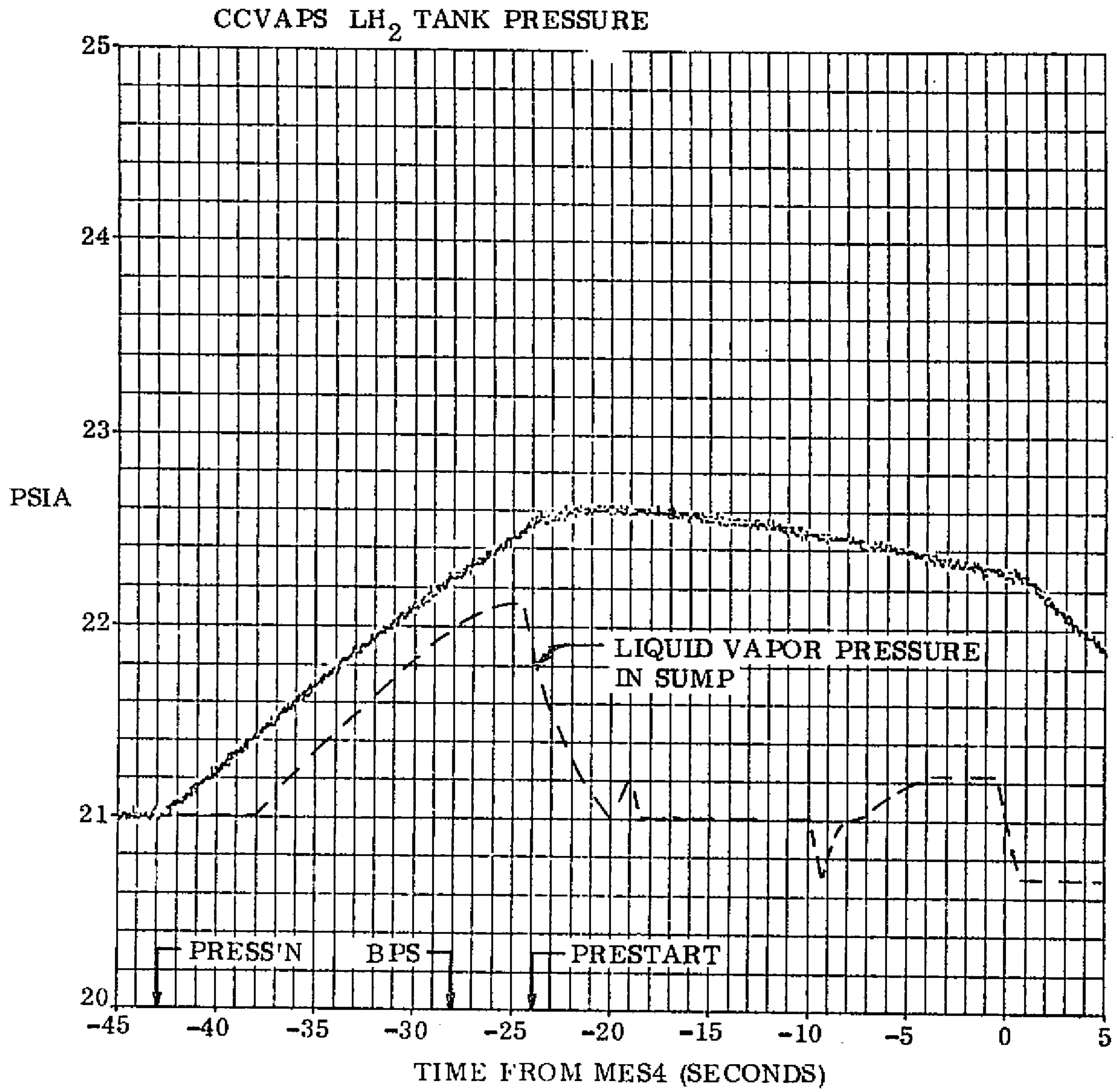
LH_2 BOOST PUMP NPSP FOR MES3



PRE-MES4 LH2 BOOST PUMP NPSP CONDITIONS

- LH2 INITIALLY SATURATED AT TANK PRESSURE
- NPSP = 0.3 PSID AT BPS
  MINIMUM NPSP CONDITION
- NPSP = 0.6 PSID AT BPS + 4 SECONDS (PRESTART)
- NPSP = 1.6 PSID AT BPS + 8 SECONDS
  WARM LH2 IS BEING PUMPED FROM SUMP AND REPLACED BY COOLER LIQUID
- NPSP = 1.1 PSID AT MES4
- NPSP = 1.2 PSID AT MES4 + 5 SECONDS
  COLD LIQUID IS BEING PUMPED OVERBOARD

LH_2 BOOST PUMP NPSP FOR MES4



SUMMARY OF PROPELLANT TANK PRESSURIZATION

- PRE-MES1 PRESSURIZATION SAME AS FOR TC-1, -3, AND -4.
- PRE-MES2 PRESSURE RISE RATES LOWER THAN THE PREDICTION BAND.
- UNEXPECTED PRESSURE INCREASES OCCURRED IN BOTH TANKS FOLLOWING PRE-MES2 RAMP PRESSURIZATION. THE LH_2 TANK PRESSURE RISE WAS NOT SEEN BECAUSE OF TELEMETRY LOSS. TC-3 FLIGHT CLEARLY SHOWED THESE PRESSURE INCREASES. THIS PHENOMENON HAS BEEN EXPLAINED.
- PRE-MES3 AND 4 LO_2 TANK PRESSURE RISE RATES GREATER THAN THE PREDICTION BAND.
- PRE-MES3 AND 4 LH_2 TANK PRESSURE RISE RATES WERE SATISFACTORILY SIMULATED BY TANK MODEL.
- INITIAL QUANTITY OF VAPOR IN LO_2 SUMP (MAX OF 50%) RESULTED IN LOW NPSP AT BPS. PUMPING OF COOLER TANK FLUID PROVIDED SATISFACTORY NPSP THROUGHOUT BOOST PUMP OPERATION.
- INITIAL QUANTITY OF VAPOR IN LH_2 SUMP (MAX OF 43%) RESULTED IN LOW NPSP AT BPS. PUMPING OF COOLER TANK FLUID PROVIDED SATISFACTORY NPSP THROUGHOUT BOOST PUMP OPERATION.

TC-5 IMPLICATIONS

- PROPELLANT TANK PRESSURE REQUIREMENTS WILL BE SATISFIED FOR ALL MAIN ENGINE STARTS (UNTIL AVAILABLE HELIUM EXPENDED).
- NPSP CONDITIONS WILL BE SATISFACTORY THROUGH MES3. MES4 AND ON CONDITIONS ARE DISCUSSED IN SECTION IX.

TC-2 POST HELIOS EXPERIMENT DATA REVIEW

I	INTRODUCTION	HUBER
II	PROPELLANT BEHAVIOR	MERINO
III	HELIUM USAGE	MERINO
IV	PROPELLANT TANK PRESSURIZATION	MERINO
V	PROPELLANT TANK THERMODYNAMICS	MERINO
VI	COMPONENT HEATING & THERMAL CONTROL	CHRISTENSEN
VII	MAIN ENGINE SYSTEM	HUBER
VIII	H_2O_2 CONSUMPTION	HUBER
IX	BOOST PUMP POST-MECO PERFORMANCE	HUBER/MERINO
X	OVERVIEW OF OTHER SYSTEMS	HUBER

V. PROPELLANT TANK THERMODYNAMICS

- LO_2 TANK ENERGY BALANCE
- LH_2 TANK ENERGY BALANCE

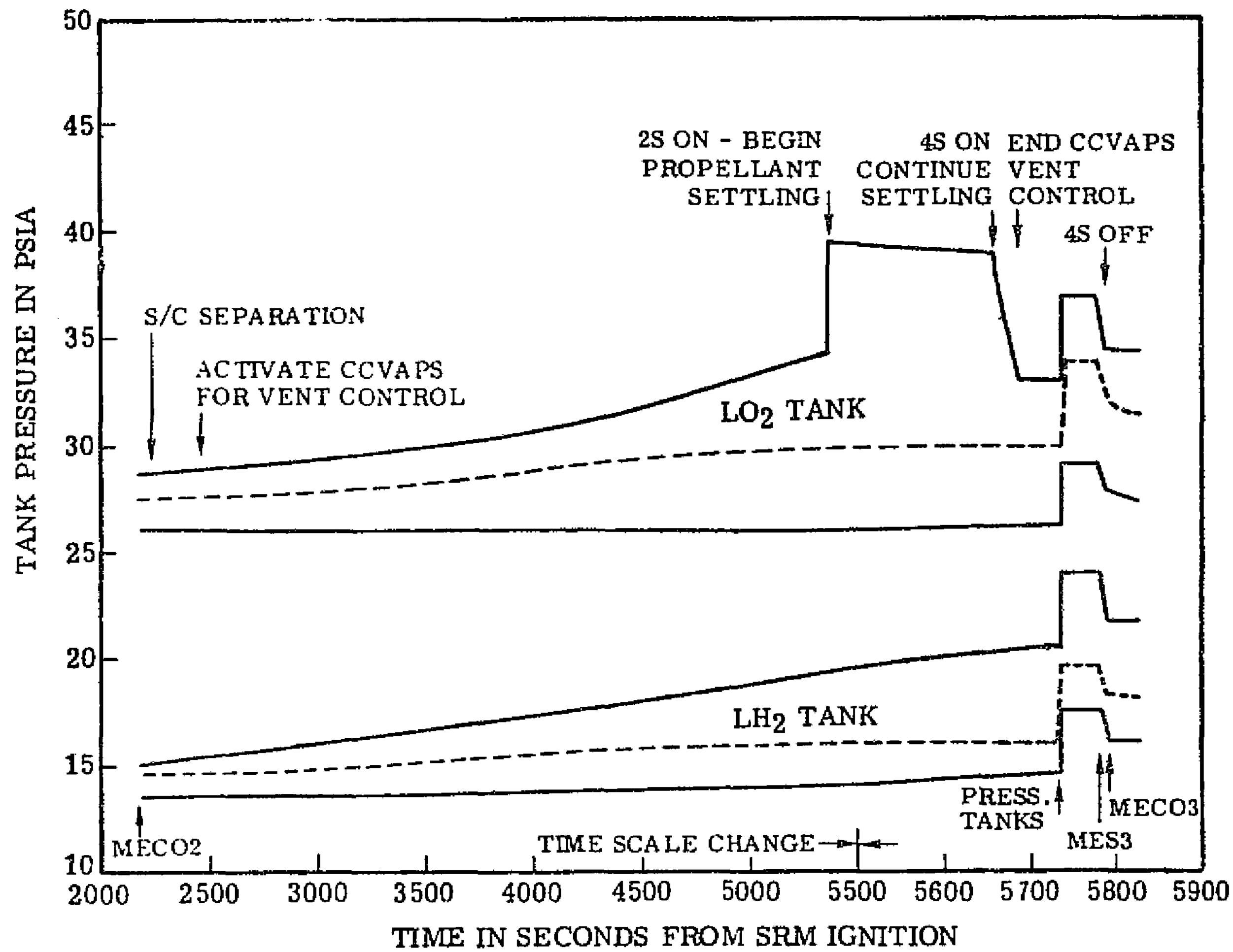
PREFLIGHT PREDICTIONS OF COAST PHASE PROPELLANT TANK PRESSURES

- MAXIMUM PRESSURE RISE RATE DURING COAST ASSUMED:
  - MAXIMUM HEATING
  - LIQUID INSTANTANEOUSLY POSITIONED FORWARD (FOR LO_2 TANK, 750 SECOND THRUST BARREL DRAIN ASSUMED)
  - DRY TANK WALLS
  - ENERGY ABSORBED BY DRY TANK WALLS RESULTS IN LIQUID BOILING DURING PROPELLANT SETTLING

- MINIMUM PRESSURE RISE RATE DURING COAST ASSUMED:
  - MINIMUM HEATING
  - THERMODYNAMIC EQUILIBRIUM

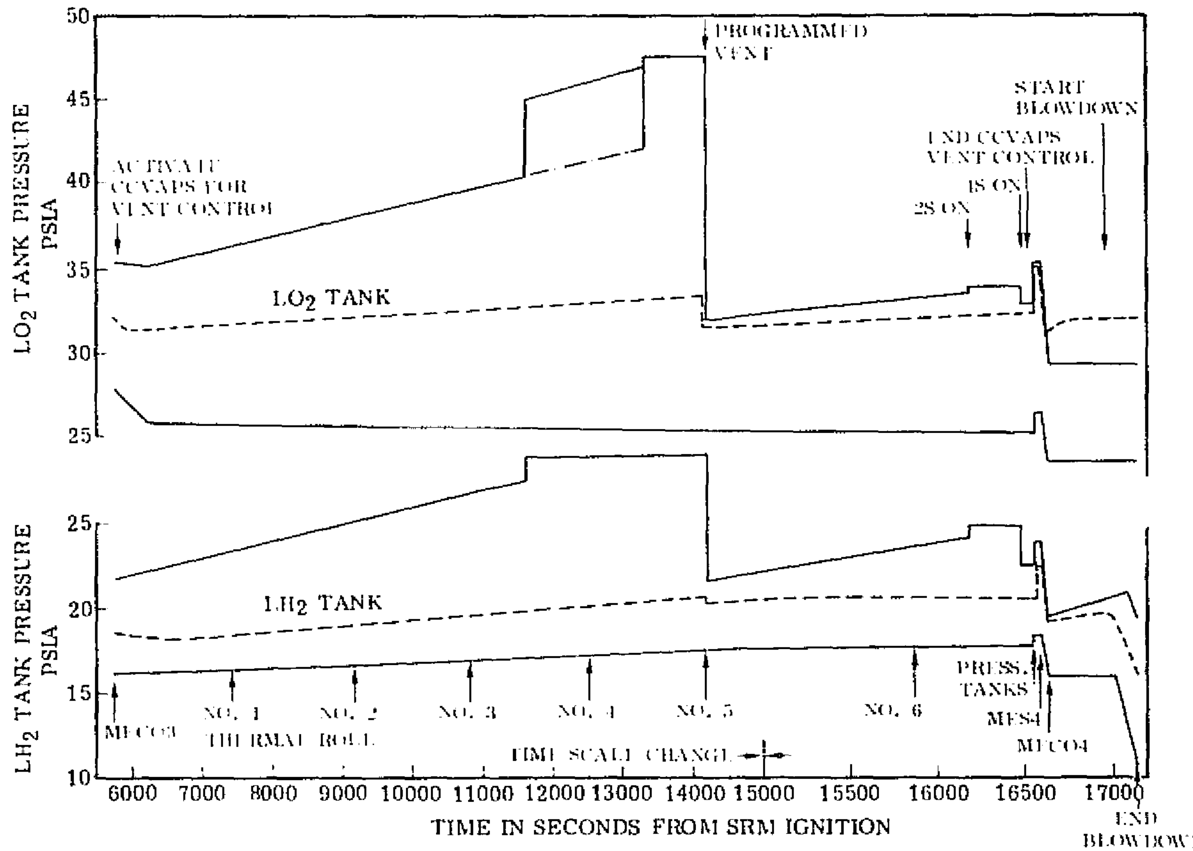
- THE ABOVE ASSUMPTIONS WERE MADE TO MAXIMIZE THE MISSION PRESSURE ENVELOPE.

PROPELLANT TANKS PRESSURE PROFILE
SECOND COAST AND THIRD BURN



NOTE: Solid lines define the maximum and minimum predicted level.
Dotted lines describe the actual flight data.

PROPELLANT TANKS PRESSURE PROFILE
THIRD COAST & FOURTH BURN



NOTE: SOLID LINES DEFINE THE MAXIMUM AND MINIMUM PREDICTED LEVELS.
DOTTED LINES DESCRIBE THE ACTUAL FLIGHT DATA.

PROPELLANT TANK ENERGY BALANCE

- FROM THE FIRST LAW:

$$[(mu)_L + (mu)_g]_2 - [(mu)_L + (mu)_g]_1 = \Delta Q_{2-1} - (hm)_{g\ out} - (hm)_{L\ out}$$

WHERE m = FLUID MASS, LB

u = FLUID INTERNAL ENERGY, BTU/LB

h = FLUID ENTHALPY, BTU/LB

ΔQ = NET HEAT INPUT TO PROPELLANT TANK, BTU

SUBSCRIPTS

2 = CONDITIONS AT MECO4 OR PRE-PROGRAMMED VENT

1 = CONDITIONS AT MECO2

g = GO_2, GH_2

L = LO_2, LH_2

out = PROPELLANT EXPELLED FROM TANK

- u, h, mg, mg_{out} ~ ARE DETERMINED FROM FLUID PRESSURES AND TEMPERATURES
- m_L ~ IS KNOWN FROM PU AND ENGINE FLOW DATA
- ΔQ CONSISTS OF TANK HEAT INPUT (+) BOOST PUMP RELATED HEAT ADDITION (-) HEAT LOSS THROUGH INTERMEDIATE BULKHEAD
- BOOST PUMP RELATED HEAT ADDITION:

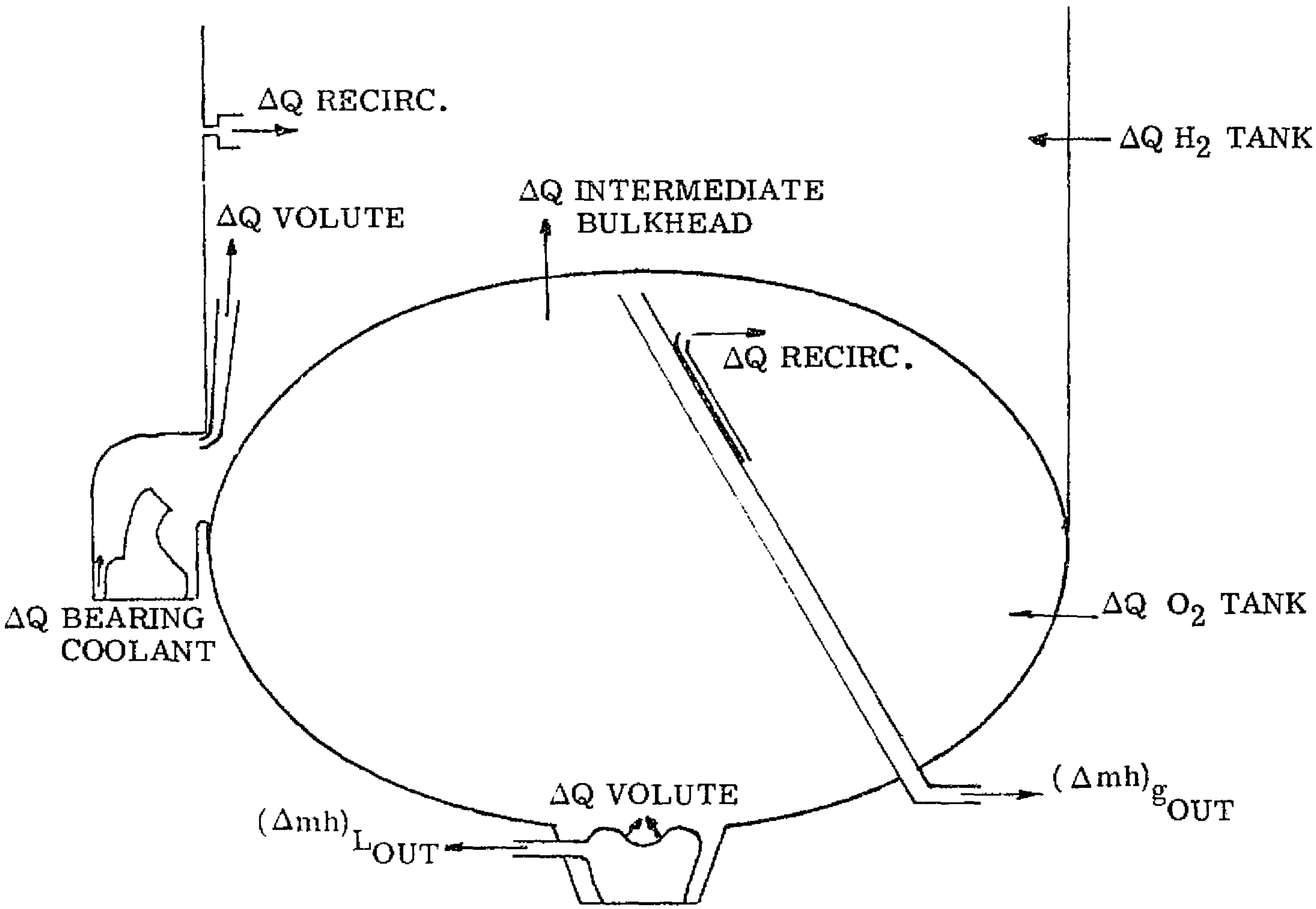
RECIRCULATION LINE FLOW (BPS TO MECO3) ~ 12 BTU (LO_2 TANK), 22 BTU (LH_2 TANK)

(BPS TO MECO4) ~ 18 BTU (LO_2 TANK), 39 BTU (LH_2 TANK)

BOOST PUMP SPINDOWN ~ 88.0 BTU PER SPINDOWN (LO_2 TANK)

~100.0 BTU PER SPINDOWN (LH_2 TANK)

PROPELLANT TANK BOUNDARIES FOR ENERGY BALANCE



LO_2 TANK ENERGY BALANCE

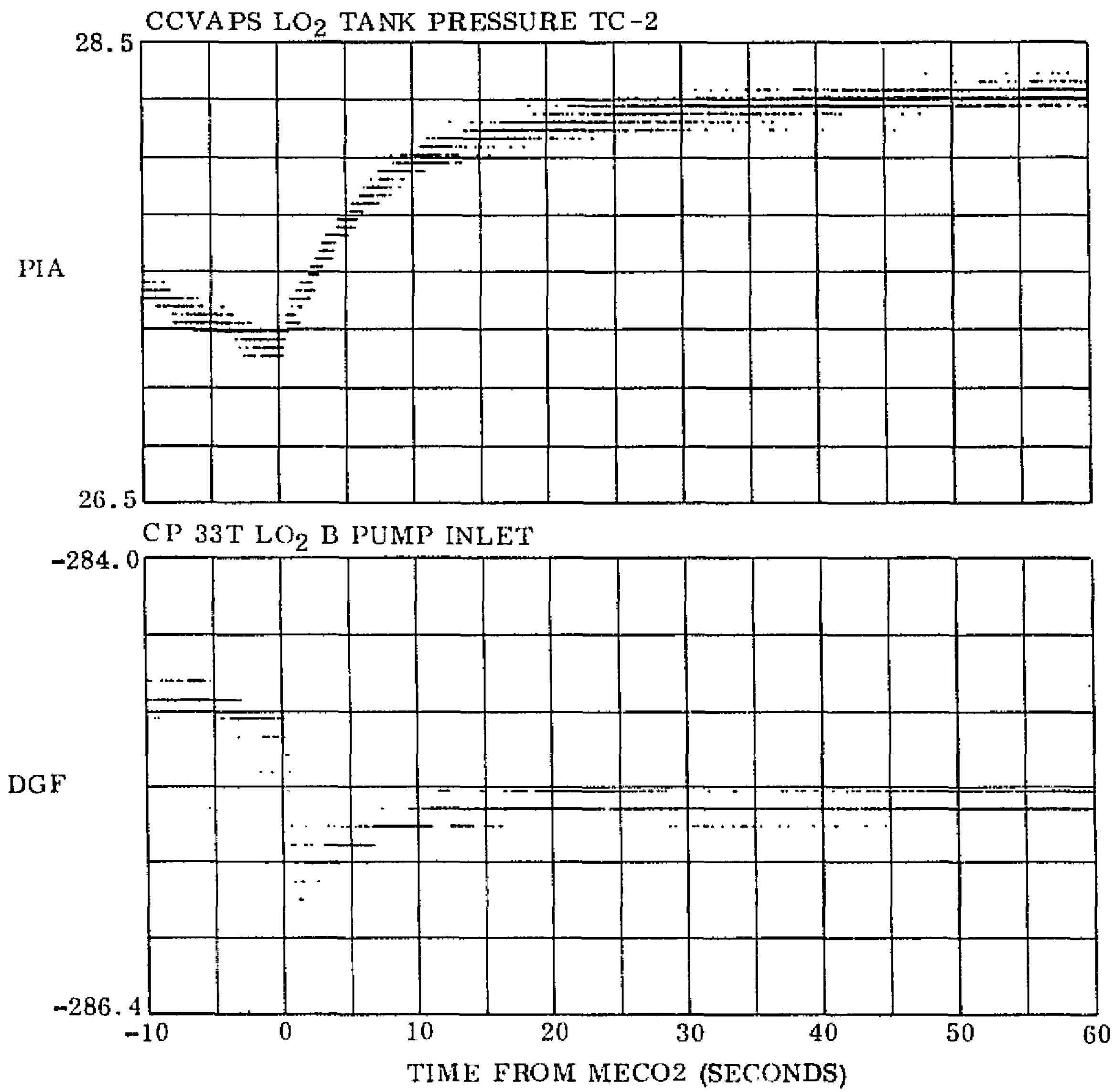
MECO2 CONDITIONS

- ULLAGE PRESSURE = 27.12 PSIA
- HELIUM PRESSURE = 0.45 PSIA
- GO_2 PRESSURE = 26.67 PSIA
- GO_2 TEMPERATURE = SATURATED AT 27.12 PSIA ($\Delta Tg = 0.3^{\circ}R$)
- GO_2 MASS = 153.7 LB.
- LO_2 VAPOR PRESSURE = 27.65 PSIA (ULLAGE PRESSURE + ρgH EFFECT)
  MAXIMUM STORED ENERGY = 640 BTU (DUE TO ρgH EFFECT)
- LO_2 MASS = 4027.6 LB (FROM PU CALCULATIONS)
- VEHICLE ACCELERATION - 2.14 G'S
- FLIGHT TIME = T + 2172.93 SECONDS

POST MECO2 CONDITIONS

- PRESSURE RECOVERY OF 1.15 PSID CAUSED BY EVAPORATION OF 6.5 LB LO_2
- $0.97^{\circ}R$ TEMPERATURE DROP INDICATES AN LO_2 VAPOR PRESSURE DECAY FROM 28.65 PSIA TO 27.30 PSIA AT BOOST PUMP INLET

LO_2 CONDITIONS AT MECO2



LO_2 TANK ENERGY BALANCE

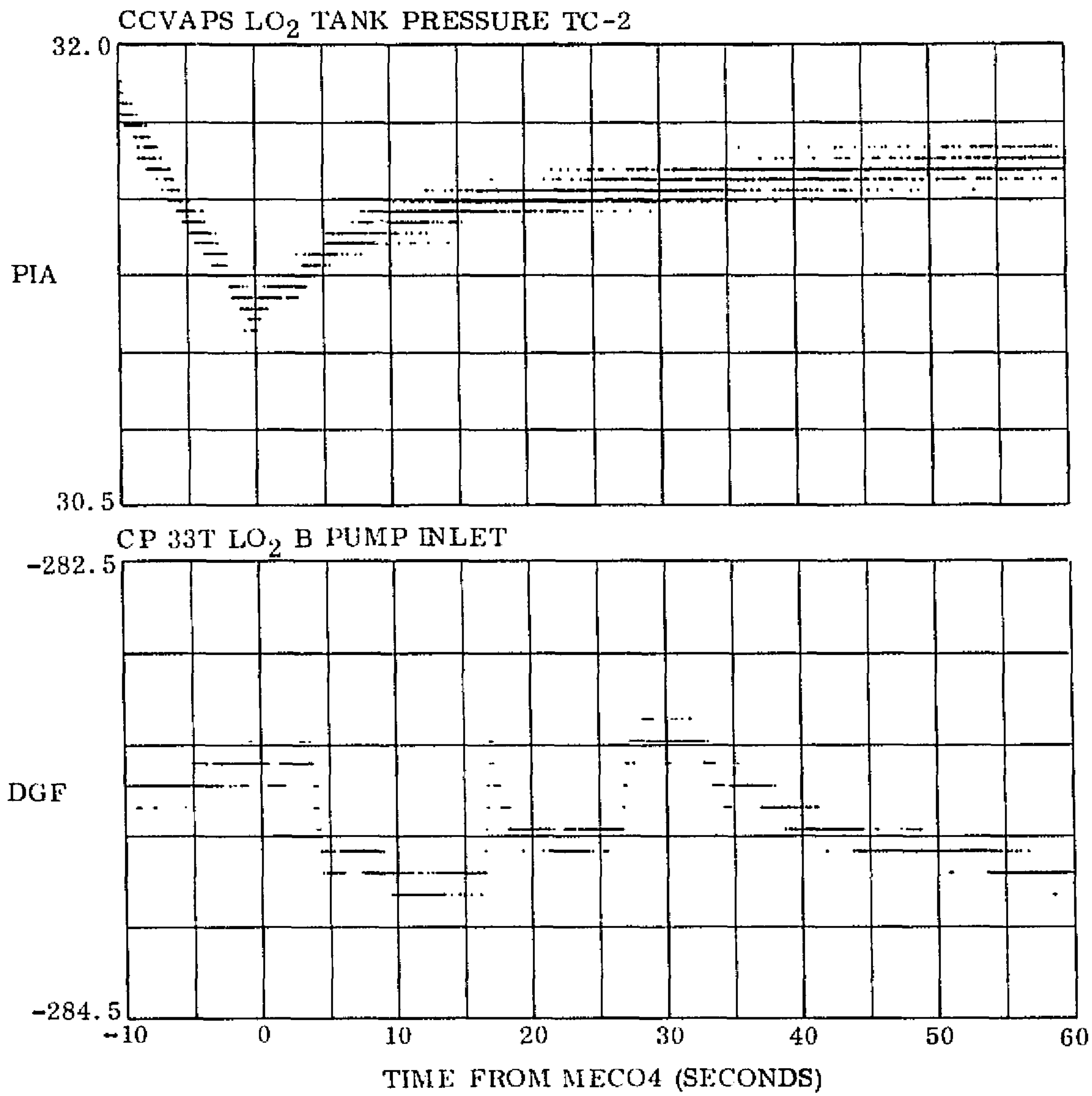
MECO 4 CONDITIONS

- ULLAGE PRESSURE = 31.09 PSIA
- HELIUM PRESSURE = 2.09 PSIA
- GO_2 PRESSURE = 29.01 PSIA
- GO_2 TEMPERATURE = 175.6 R (0.6°R SUPERHEAT)
- GO_2 MASS = 190.3 LB
- LO_2 VAPOR PRESSURE = 30.07 PSIA
- LO_2 MASS = 790.5 LB (FROM PU CALCULATIONS)
- VEHICLE ACCELERATION = 4.62 G'S
- FLIGHT TIME = T + 16631.98 SECONDS

POST MECO 4 CONDITIONS

- PRESSURE RECOVERY OF 0.51 PSID CAUSED BY EVAPORATION OF 2.2 LB LO_2
- 0.38°R TEMPERATURE DROP INDICATES A LO_2 VAPOR PRESSURE DECAY FROM 31.1 PSIA TO 29.5 PSIA AT BOOST PUMP INLET.

LO_2 CONDITIONS AT MECO4



LO_2 TANK ENERGY BALANCE

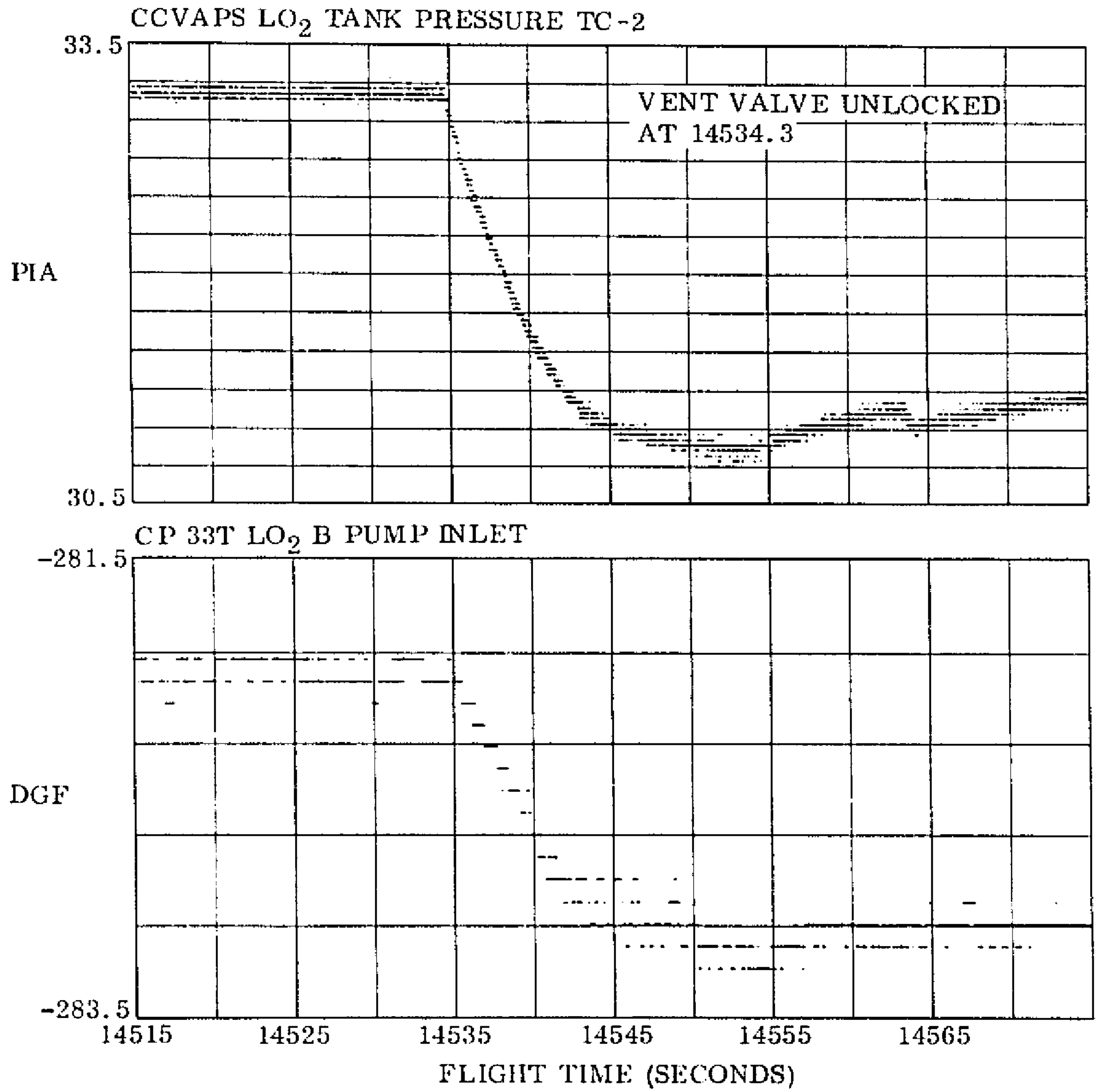
PROPELLANT CONDITIONS AT VENT TERMINATION

- ULLAGE PRESSURE = 30.82 PSIA
- HELIUM PRESSURE = 1.45 PSIA
- GO_2 PRESSURE = 29.37 PSIA
- GO_2 TEMPERATURE = 175.6°R (0.3°R SUPERHEAT)
- GO_2 MASS = 173.0 LB
- LO_2 VAPOR PRESSURE = 30.65 PSIA
- LO_2 MASS = 3350.3 LB
- VEHICLE ACCELERATION = 2.4×10^{-3}
- FLIGHT TIME = T + 14554 SECONDS
- GO_2 VENT MASS = 12.1 LB
- HELIUM VENT MASS = 0.07 LB

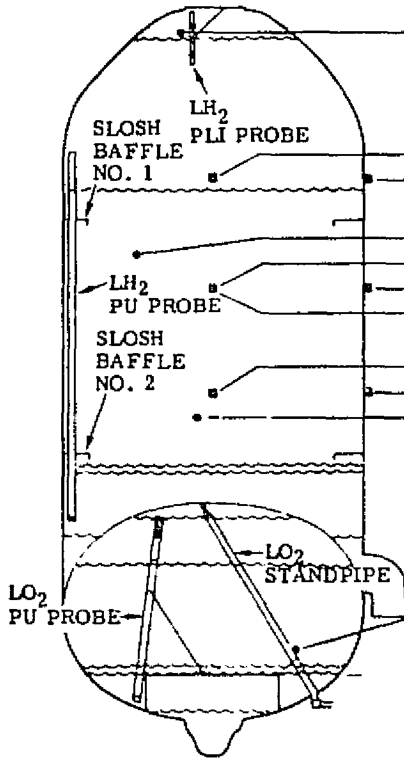
POST VENT CONDITIONS

- PRESSURE RECOVERY OF 0.93 PSID CAUSED BY EVAPORATION OF 4.0 LB LO_2.
- 1.36 °R TEMPERATURE DROP INDICATES AN LO_2 VAPOR PRESSURE DECAY FROM 32.92 PSIA TO 30.82 PSIA AT BOOST PUMP INLET.

LO_2 CONDITIONS DURING PRE-PROGRAMMED VENT



TEMPERATURE MEASUREMENT LOCATIONS



MEASUREMENT NUMBER (1)	LOCATION	
	STATION	RADIAL
CF24T	2473	330
CA288T	2426	0
CA289T	2426	90
CF25T	2[illegible]7	310
CA290T	2370	0
CA291T	2370	90
CA292T	2370	180
CA293T	2334	0
CA294T	2334	90
CF27T	2320	195
CF23T	2230	60

NOTES: (1)
CF MEASUREMENTS (•) INTERNAL TO TANKS.
CA MEASUREMENTS (▪) MOUNTED ON EXTERNAL SURFACE OF LH$_2$ TANK.

LO_2 TANK ENERGY BALANCE

ULLAGE TEMPERATURE CONDITIONS FROM MECO 2 TO MECO 4

- MECO 2 ~ ULLAGE TEMPERATURE = 173.64°R

- POST MECO2 ~ ULLAGE TEMPERATURE INCREASES TO 174.59°R

  NOTE: THE INCREASING ULLAGE TEMPERATURE WAS CAUSED BY EVAPORATION WHICH REDUCED LIQUID TEMPERATURE DURING THE SAME PERIOD.

- VENT VALVE UNLOCK ~ ULLAGE TEMPERATURE = 177.0°R
- VENT TERMINATION ~ ULLAGE TEMPERATURE DROPS TO 175.6°R
- POST VENT ~ ULLAGE TEMPERATURE INCREASES TO 176.5°R

  NOTE: ULLAGE TEMPERATURE CHANGES ARE CONSISTENT WITH VENTING OF A NEARLY SATURATED VAPOR FOLLOWED BY LO_2 EVAPORATION WHICH RESULTS IN A VAPOR TEMPERATURE INCREASE.

- MECO 4 ~ ULLAGE TEMPERATURE = 175.6°R

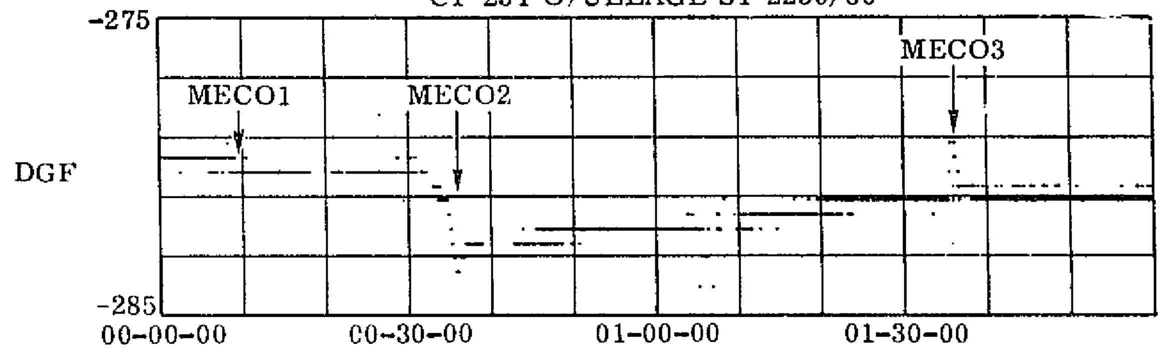
- POST MECO4 ~ ULLAGE TEMPERATURE INCREASES TO 176.3°R

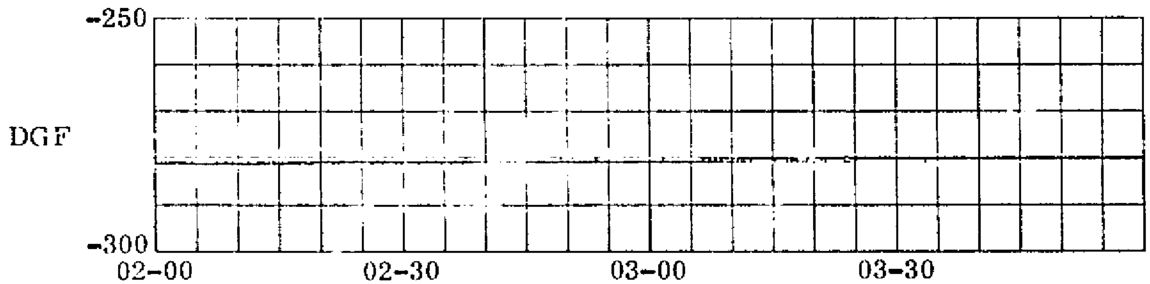
  NOTE: THE INCREASING ULLAGE TEMPERATURE WAS CAUSED BY EVAPORATION WHICH REDUCED LIQUID TEMPERATURE DURING THE SAME PERIOD.

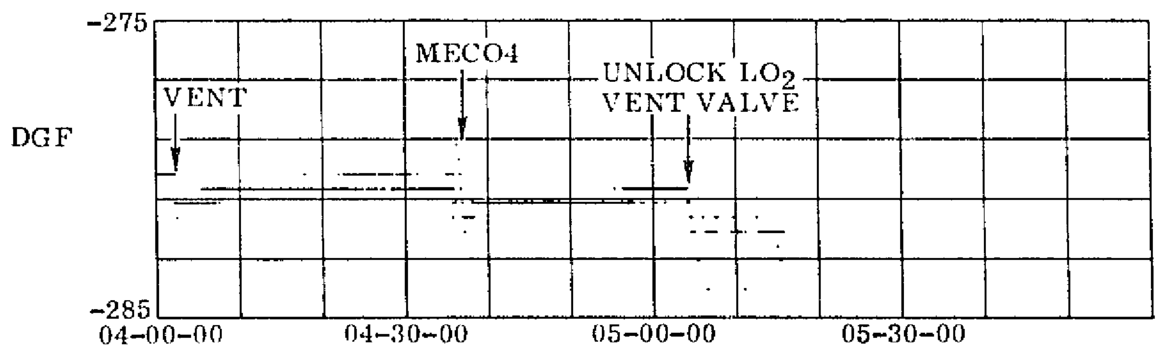
LO_2 TANK ULLAGE TEMPERATURES DURING MISSION

GENERAL DYNAMICS
Convair Division
31 Oct 75

CF 23T O/ULLAGE ST 2230/60







NET HEAT INPUT TO LO_2 TANK

- FIRST LOW EQUATION SOLVED FOR ΔQ_{NET}
- ΔQ TANK = ΔQ NET - 88 BTU (PER B/P SPINDOWN) - RECIRC. FLOW HEAT ADDITION

  = TANK HEAT INPUT - INTERMEDIATE BULKHEAD HEAT LOSS

MECO 2 TO MECO 4 CONDITIONS

- $\Delta Q\ \text{TANK} = \dot{Q}_{\text{2ND COAST}}{}^{*}\ (1.0\ \text{HRS}) + \dot{Q}_{\text{3RD COAST}}{}^{*}\ (3.0\ \text{HRS})$

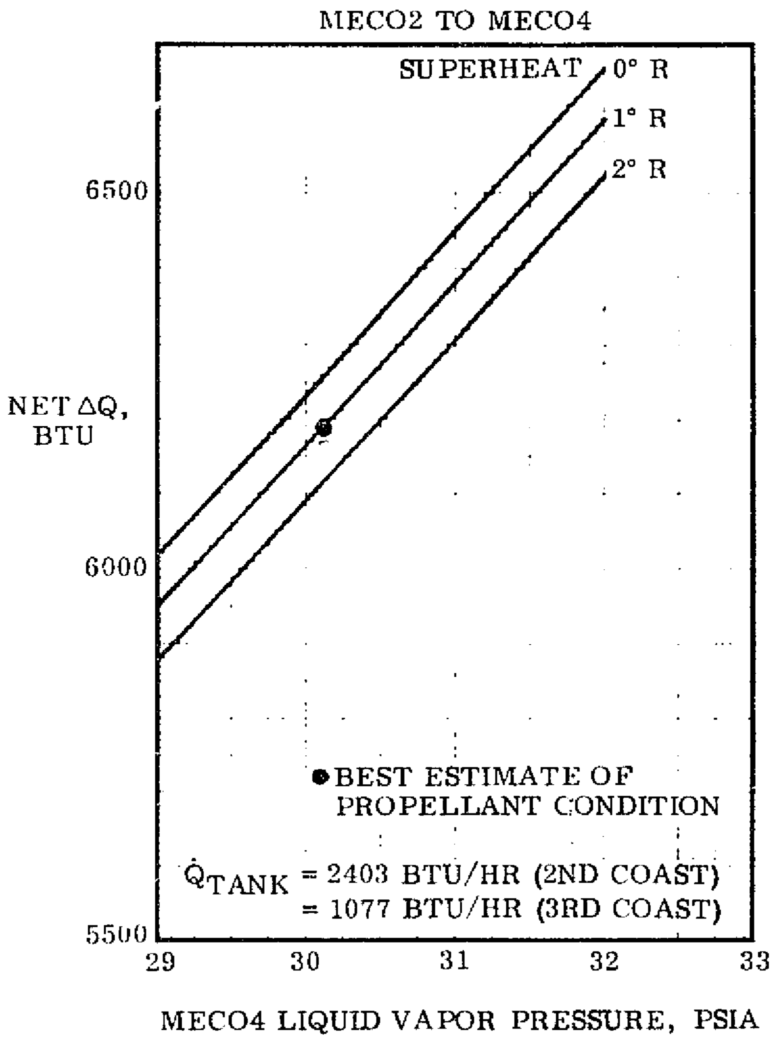
MECO 2 TO PRE-PROGRAMMED VENT CONDITIONS

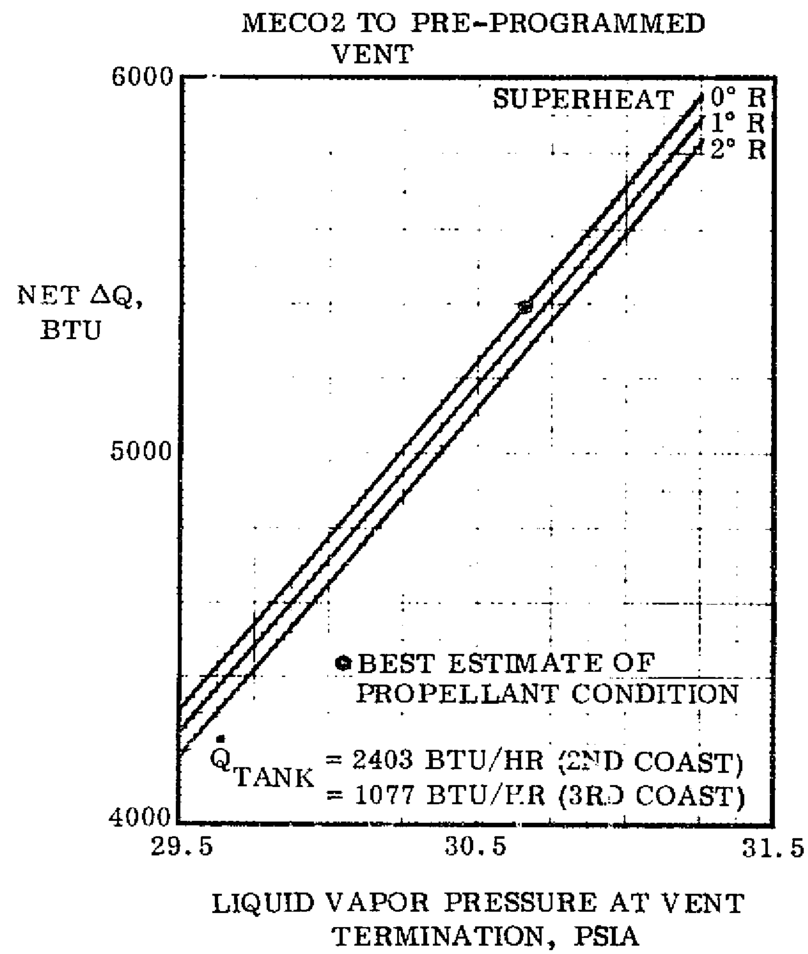
- $\Delta Q\ \text{TANK} = \dot{Q}_{\text{2ND COAST}}{}^{*}\ (1.0\ \text{HRS}) + \dot{Q}_{\text{3RD COAST}}{}^{*}\ (2.44\ \text{HRS})$

CALCULATED TANK HEATING RATES

- Q 2ND COAST = 2403 BTU/HR
- Q 3RD COAST = 1077 BTU/HR

NET HEAT INPUT TO LO_2 TANK VERSUS LIQUID VAPOR PRESSURE AND ULLAGE SUPERHEAT CONDITIONS





SUMMARY OF LO_2 TANK THERMODYNAMIC CONDITIONS FROM MECO2 TO MECO4

- CALCULATED TANK HEATING RATES ARE EMPLOYED TO DETERMINE INTERMEDIATE STATE CONDITIONS.
- TABULATED INTERMEDIATE STATE CONDITIONS ARE OBTAINED FROM ENERGY BALANCE.

CONCLUSIONS

- HELIUM PURGES CONTRIBUTED TO AN INCREASED OXYGEN EVAPORATION DURING THE COASTS.
- HELIUM PURGE INFLUENCE ON COAST PHASE TANK PRESSURE RISE WAS SMALL.
- HELIUM FLOW CHILLED LO_2 BULK BY $\approx 0.5°R$ FOR 3RD PRESSURIZATION AND RESULTED IN LOWER PRESSURE RISE RATE DURING 3RD COAST THAN DURING THE 2ND COAST.
- INTERMEDIATE BULKHEAD HEAT TRANSFER RATE IS $\approx$ 1000 BTU/HR.
- NEAR THERMAL EQUILIBRIUM CONDITIONS WERE AIDED BY H_2O_2 MOTOR FIRINGS WHICH RESULTED IN ΔP DECAYS OF UP TO 0.2 PSID.

TC-5 APPLICATION

- HELIUM PURGE INFLUENCE ON COAST PHASE TANK PRESSURE RISE WILL BE SMALL.
- 5-1/4 HOUR COAST PRESSURE RISE RATE WILL BE SIMILAR TO THE TC-2 3RD COAST PRESSURE RISE RATE.
- SIXTH COAST PRESSURE RISE RATE WILL BE TWO TIMES GREATER THAN FOR 5-1/4 HOUR COAST BECAUSE OF REDUCED LO_2 MASS AND POTENTIAL FOR PARTIALLY DRY AFT BULKHEAD.

TC-2 MISSION LO_2 TANK THERMODYNAMIC CONDITIONS

	MECO2	PRE-MES3	MES3	MECO3	PRE-VENT	END VENT	POST VENT	PRE-MES4	MES4	MECO4	POST MECO4
TANK PRESSURE, PSIA	27.12	29.89	33.40	32.00	33.13	30.82	31.75	32.50	35.40	31.09	31.60
OXYGEN PRESSURE, PSIA	26.67	29.35	32.02	30.66	31.58	29.37	30.30	31.00	33.10	29.01	29.52
HELIUM PRESSURE, PSIA	0.45	0.54	1.38	1.34	1.55	1.45	1.45	1.50	2.30	2.08	2.08
LIQUID PRESSURE, PSIA	27.65	28.83	28.16	28.16	30.70	30.65	30.25	30.9	30.24	30.07	29.35
LIQUID MASS, LB.	4027.6	4012.5	3929.4	3359.4	3351.7	3350.3	3345.5	3341.9	3276.0	766.0	750.4
VAPOR MASS, LB	153.7	167.8	180.0	180.0	183.7	173.0	177.0	181.4	190.3	190.3	192.5
HELIUM MASS, LB.	0.306	[illegible]	0.937	0.937	1.082	1.009	1.009	1.046	1.613	1.614	1.614
VAPOR TEMPERATURE, °R	173.7	175.6	179.5	176.3	178.0	175.6	176.5	177.1	180.7	175.6	176.30
VAPOR SUPERHEAT, °R	0.3	0.4	2.5	0.2	1.3	0.3	0.7	0.7	3.0	0.6	1.0

LO_2 EXPULSION, LB.	1	71	570	2	0	0	0	57	2510	13
VAPOR VENT, LB.	0	0	0	0	12.1	0	0	0	0	0
NET HEAT RATE TO TANK, BTU/HR.	← 2403 →				← 1077 →					

LH_2 TANK ENERGY BALANCE

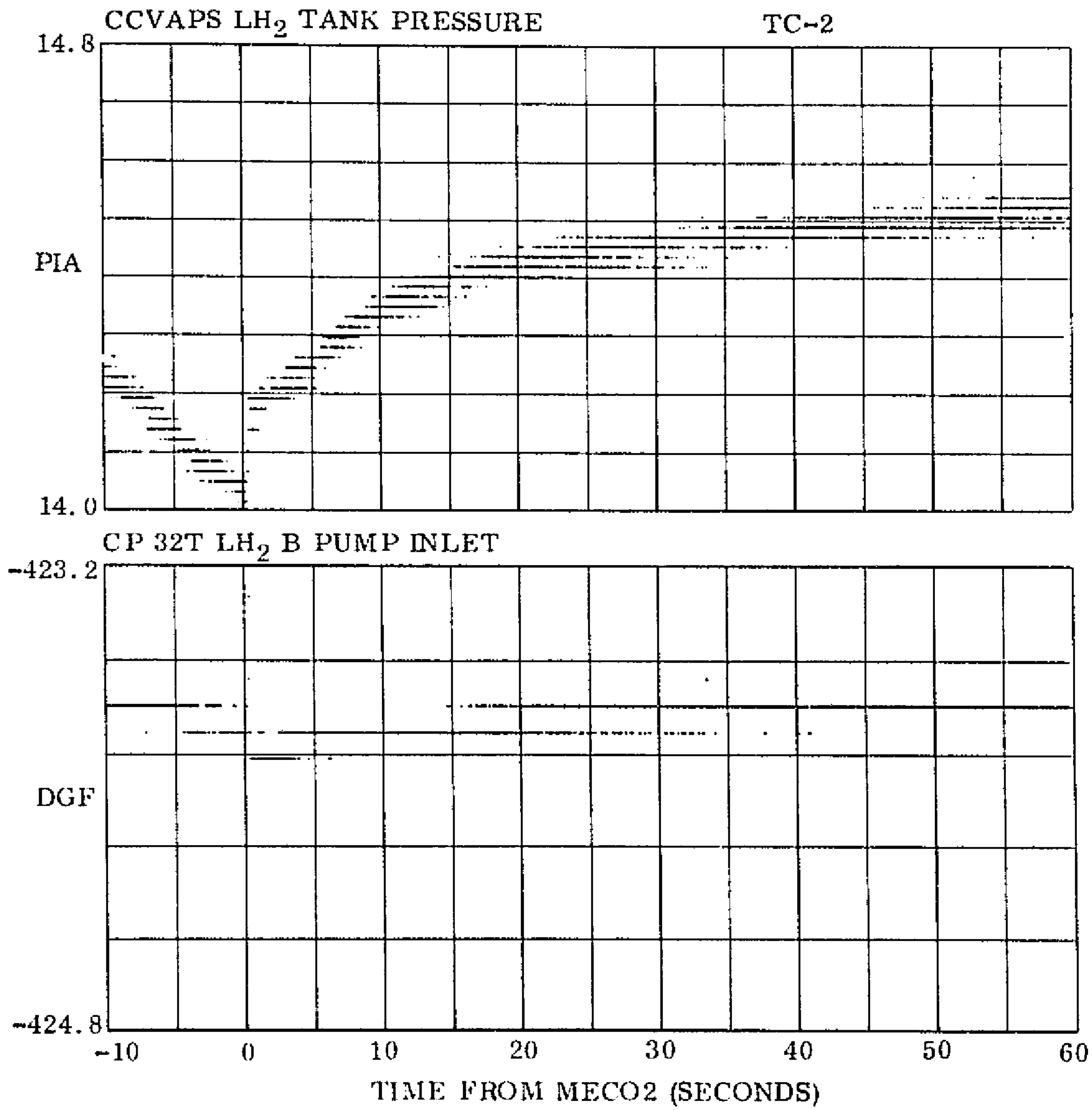
MECO2 CONDITIONS

- ULLAGE PRESSURE = 14.11 PSIA
- HELIUM PRESSURE = 0.13 PSIA
- GH_2 PRESSURE = 13.98 PSIA
- GH_2 TEMPERATURE = SATURATED AT 14.11 PSIA ($\Delta Tg = 0.08^{\circ}R$)
- GH_2 MASS = 81.30 LB
- LH_2 VAPOR PRESSURE = 14.23 PSIA (ULLAGE PRESSURE + ρgH EFFECT
  MAXIMUM STORED ENERGY = 132 BTU (DUE TO ρgH EFFECT)
- LH_2 MASS = 1131.2 LB (FROM PU CALCULATIONS)
- VEHICLE ACCELERATION = 2.14 G'S
- FLIGHT TIME = T + 2172.93 SECONDS

POST MECO 2 CONDITIONS

- PRESSURE RECOVERY OF 0.5 PSID CAUSED BY EVAPORATION OF 2.16 LB LH_2.
- $0.094^{\circ}R$ TEMPERATURE DROP INDICATES AN LH_2 VAPOR PRESSURE DECAY FROM 14.24 PSIA TO 14.00 PSIA AT BOOST PUMP INLET.

LH_2 CONDITIONS AT MECO2



LH_2 TANK ENERGY BALANCE

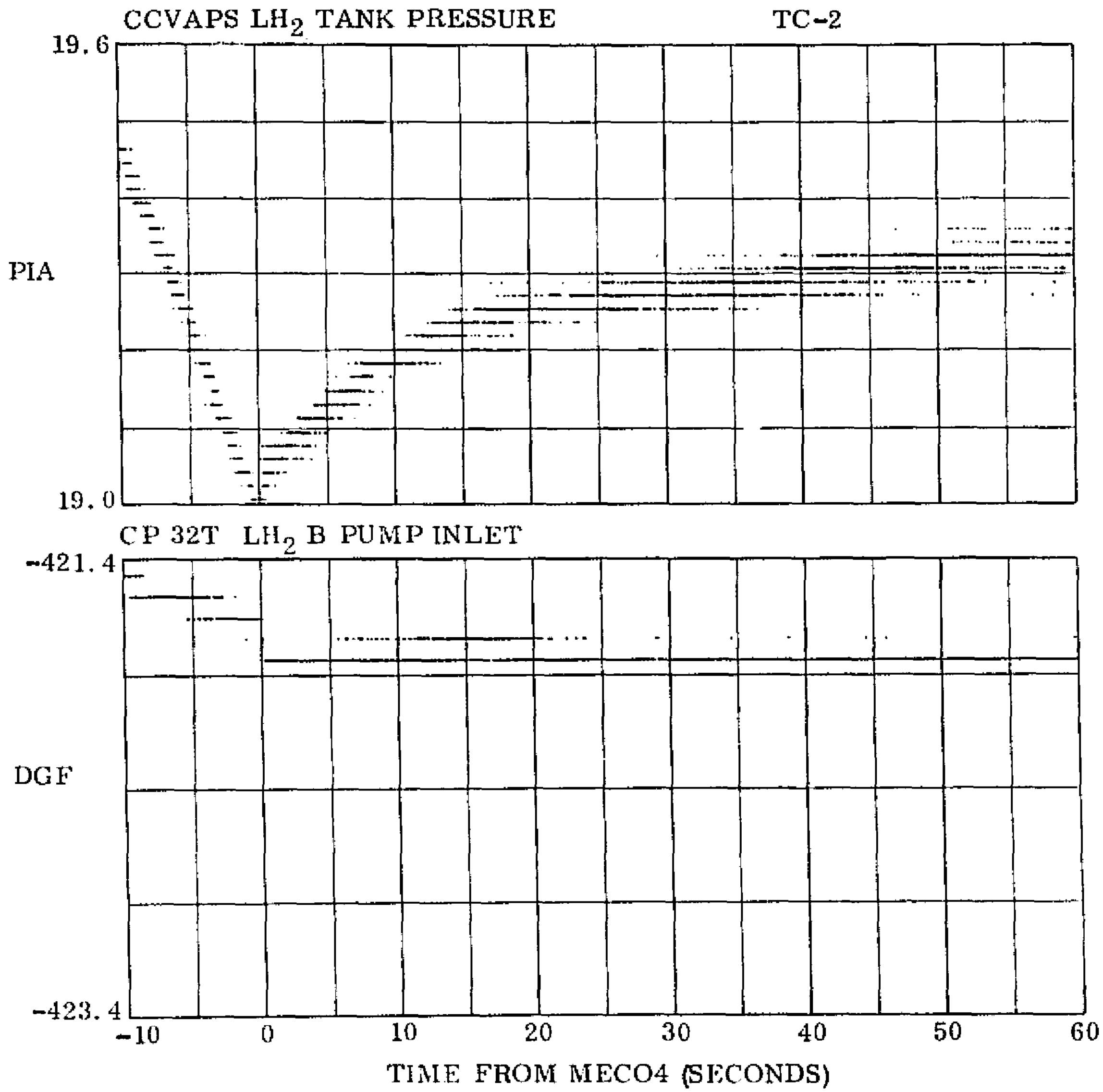
MECO 4 CONDITIONS

•	ULLAGE PRESSURE	= 19.10 PSIA
•	HELIUM PRESSURE	= 0.52 PSIA
•	GH_2 PRESSURE	= 18.68 PSIA
•	GH_2 TEMPERATURE	= 42.4°R (4.3°R SUPERHEAT)
•	GH_2 MASS	= 110.1 LB.
•	LH_2 VAPOR PRESSURE	= 19.10 PSIA
•	LH_2 MASS	= 329.9 LB
•	VEHICLE ACCELERATION	= 4.62 G'S
•	FLIGHT TIME	= T + 16631.98 SECONDS

POST MECO 4 CONDITIONS

- PRESSURE RECOVERY OF 0.24 PSID CAUSED BY EVAPORATION OF 0.3 LB LH_2.
- 0.188°R TEMPERATURE DROP INDICATES AN LH_2 VAPOR PRESSURE DECAY FROM 19.54 PSIA TO 19.00 PSIA AT BOOST PUMP INLET.

LH_2 CONDITIONS AT MECO4



LH_2 TANK ENERGY BALANCE

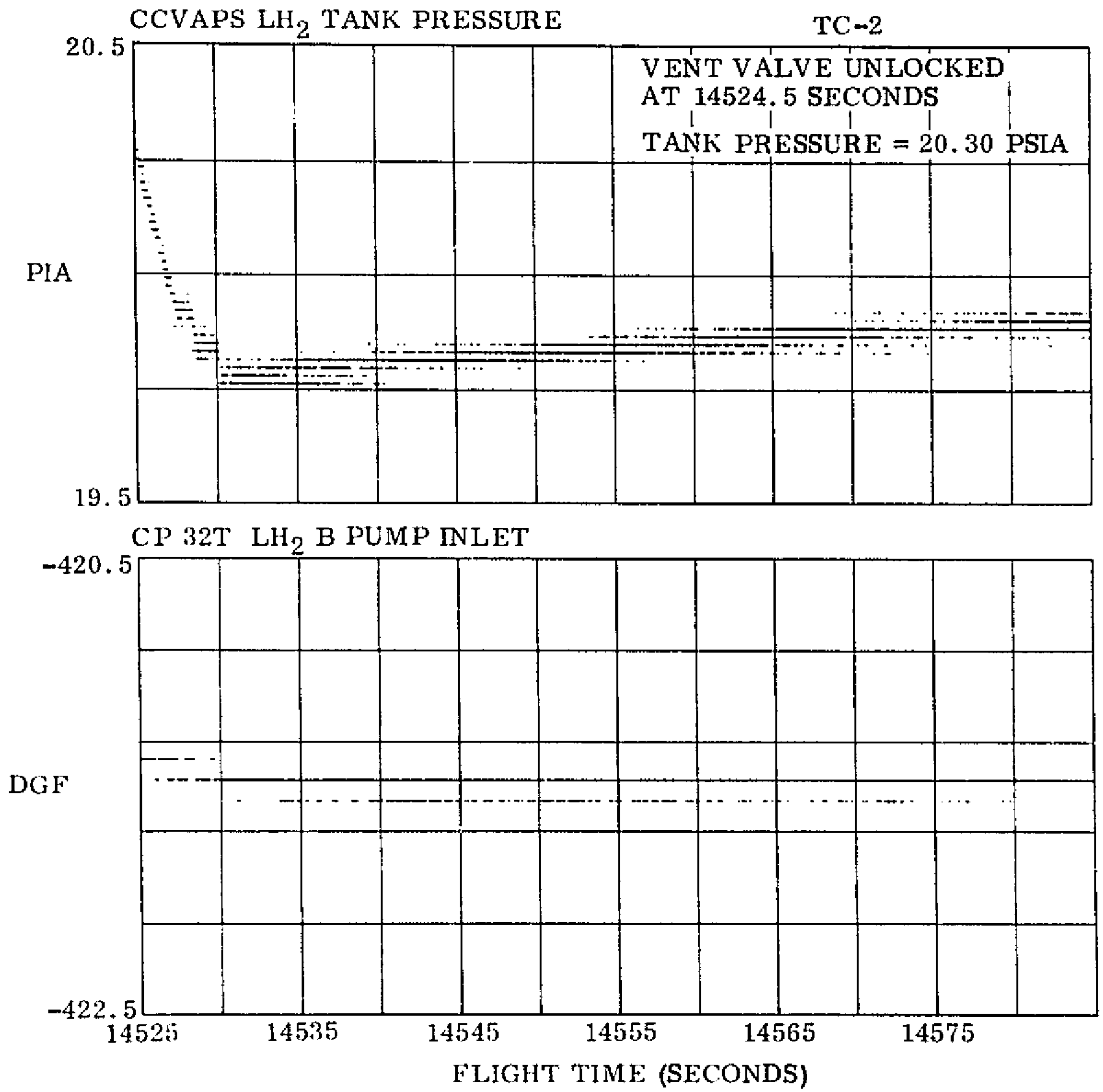
PROPELLANT CONDITIONS AT VENT TERMINATION

- ULLAGE PRESSURE = 19.88 PSIA
- HELIUM PRESSURE = 0.34 PSIA
- GH_2 PRESSURE = 19.54 PSIA
- GH_2 TEMPERATURE = 42.6°R (4.3°R SUPERHEAT)
- GH_2 MASS = 100.76 LB
- LH_2 VAPOR PRESSURE = 19.60 PSIA
- LH_2 MASS = 947.9 LB
- VEHICLE ACCELERATION = 2.4×10^{-3} G'S
- FLIGHT TIME = T + 14530 SECONDS
- GH_2 VENT MASS = 2.51 LB
- HELIUM VENT MASS = 0.09 LB

POST VENT CONDITIONS

- PRESSURE RECOVERY OF 0.12 PSID CAUSED BY EVAPORATION OF 0.53 LB LH_2.
- 0.094 °R TEMPERATURE DROP INDICATES AN LH_2 VAPOR PRESSURE DECAY FROM 20.16 PSIA TO 19.88 PSIA AT BOOST PUMP INLET.

LH_2 CONDITIONS DURING PRE-PROGRAMMED VENT



LH_2 TANK ENERGY BALANCE

ULLAGE TEMPERATURE CONDITIONS FROM MECO 2 TO MECO 3

- CF24T GENERALLY REFLECTS THE WARM ULLAGE CONDITIONS RESULTING FROM PRESSURIZATION WITH AMBIENT HELIUM. CF25T AND CF27T TEMPERATURES ARE DISCUSSED BELOW. THE INDICATED TEMPERATURES HAVE BEEN INCREASED BY 0.7°R TO REFLECT ACTUAL TEMPERATURES.

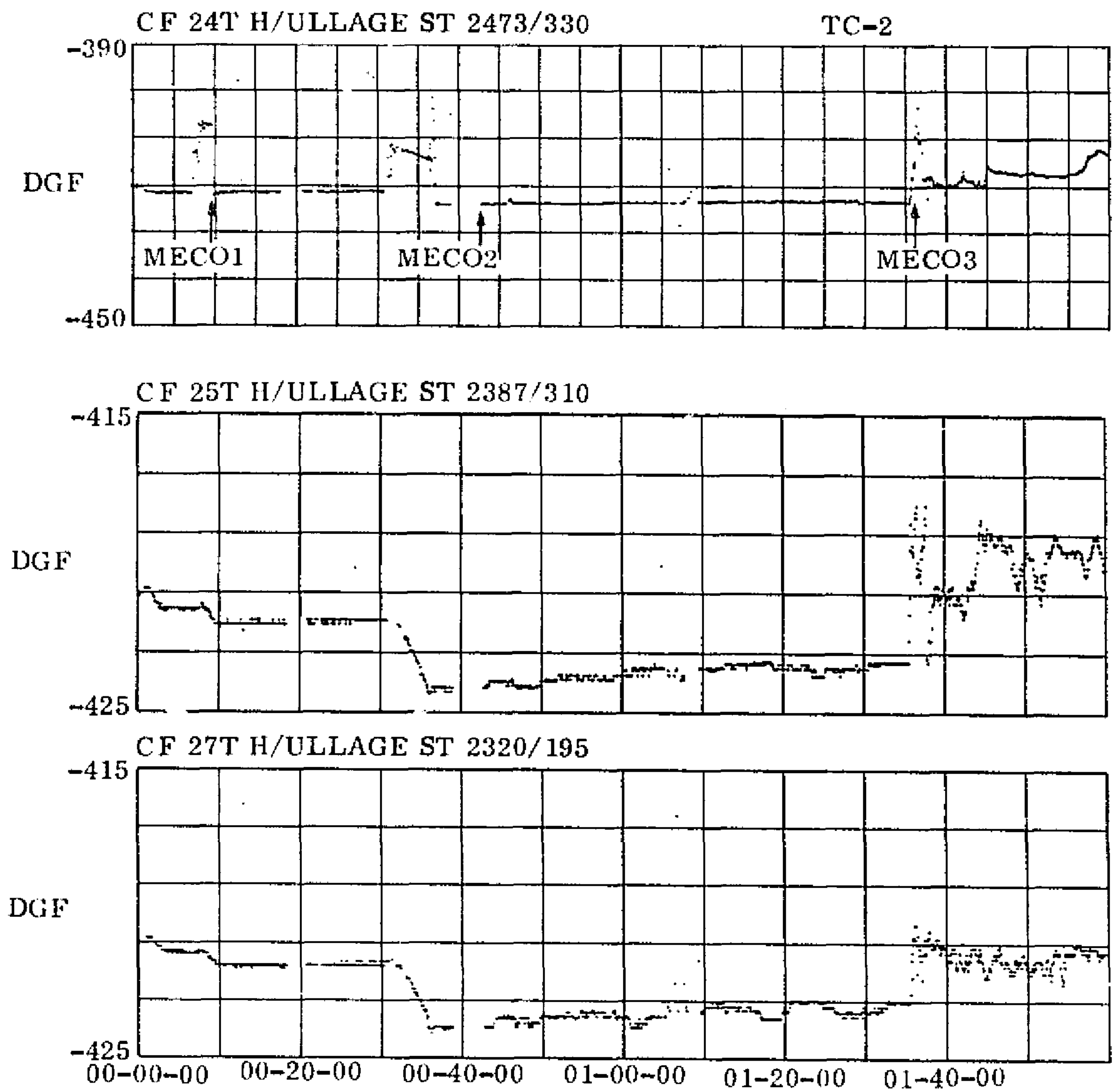
- MECO 2 ~ AVERAGE ULLAGE TEMPERATURE = 36.23°R (SATURATED AT 14.11 PSIA)

- POST MECO 2 ~ AVERAGE ULLAGE TEMPERATURE = 36.43°R

  NOTE: THE INCREASED ULLAGE TEMPERATURE WAS DUE TO THE LH_2 EVAPORATION THAT RESULTED FROM THE LOSS OF LIQUID ACCELERATION HEAD.

- 3RD PRESS'N ~ CF25T INCREASE = 5.3°R WHICH INDICATES WARM VAPOR ADJACENT TO PROBE.
  CF27T INCREASE = 2.7°R WHICH RESULTS FROM ULLAGE COMPRESSION.

LH_2 TANK ULLAGE TEMPERATURES DURING MISSION



LH_2 TANK ENERGY BALANCE

ULLAGE TEMPERATURE CONDITIONS FROM PROGRAMMED VENT TO MECO4

- VENT VALVE UNLOCK ~ AVERAGE ULLAGE TEMPERATURE = 39.12°R.
- VENT TERMINATION ~ AVERAGE ULLAGE TEMPERATURE DROPS TO 38.93°R.
- POST VENT ~ AVERAGE ULLAGE TEMPERATURE REMAINS AT 38.93°R.

NOTE: THE ULLAGE TEMPERATURE DECAY IS CONSISTENT WITH THE 0.42 PSID TANK PRESSURE DECAY DURING VENTING.

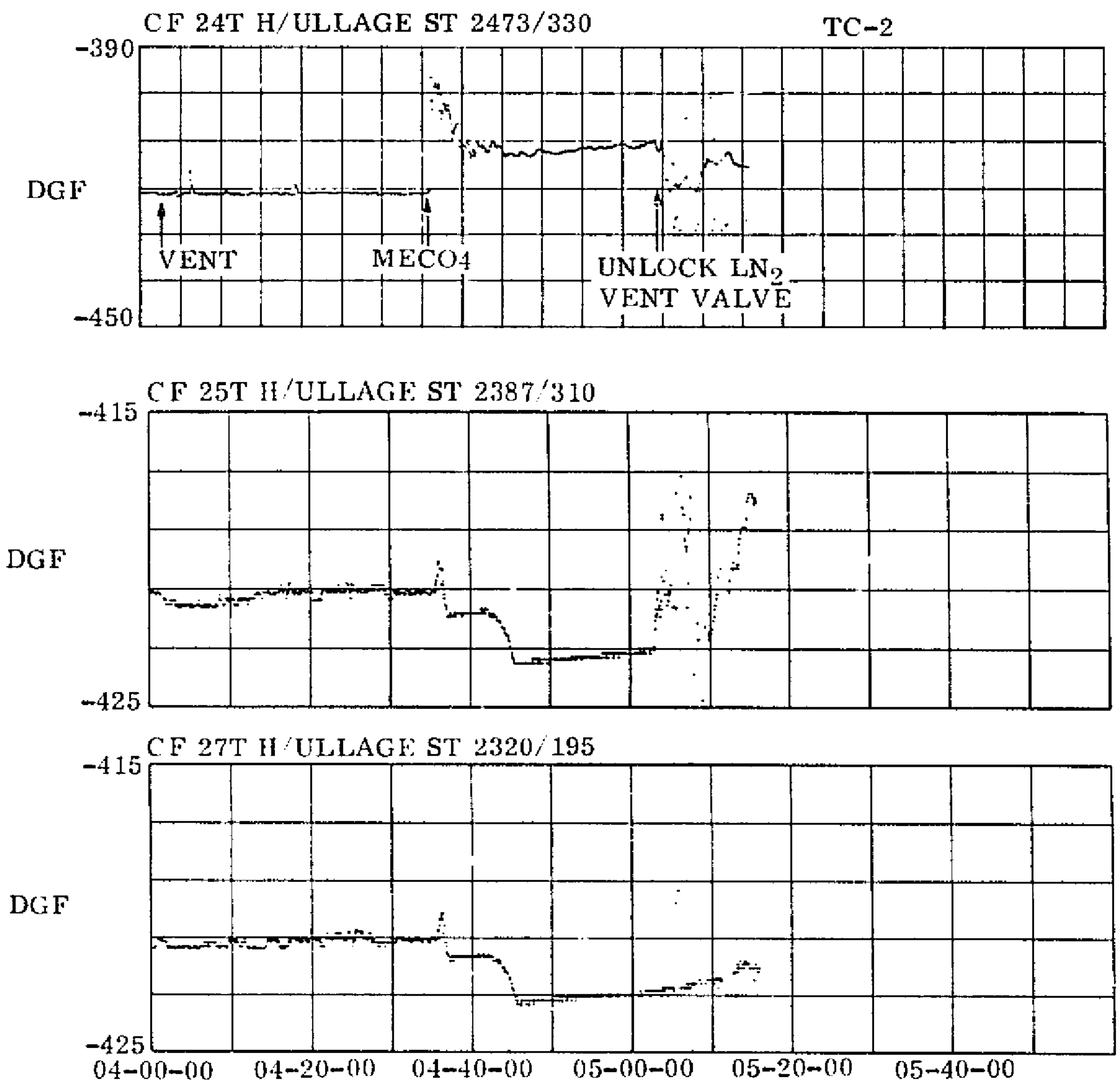
- MECO4 ~ AVERAGE ULLAGE TEMPERATURE = 38.52°R.
- POST MECO4 ~ AVERAGE ULLAGE TEMPERATURE = 38.61°R.

NOTE: THE INCREASED ULLAGE TEMPERATURE WAS DUE TO THE LH_2 EVAPORATION THAT RESULTED FROM THE LOSS OF LIQUID ACCELERATION HEAD.

- CF25T AND CF27T DID NOT DETECT THE MASS OF WARM GH_2 AND HELIUM ESTIMATED AT 250 FT^3, 17.2 LB AND 74°R.

LH2 TANK ULLAGE TEMPERATURES DURING MISSION

GENERAL DYNAMICS
Convair Division
31 Oct 75



2.2

NET HEAT INPUT TO LH_2 TANK

- FIRST LAW EQUATION SOLVED FOR ΔQ_{NET}
- $\Delta Q_{TANK} = \Delta Q_{NET} - 100$ BTU (PER B/P SPINDOWN) - (RECIRC. + VOLUTE FLOW HEAT ADDITION)

  = TANK HEAT INPUT - INTERMEDIATE BULKHEAD HEAT LOSS

MECO 2 TO MES 4 CONDITIONS (MES 4 OBTAINED FROM ENGINE BURN SIMULATION)

- $\Delta Q_{TANK} = \dot{Q}_{2ND\ COAST} * (1.0\ HRS) + \dot{Q}_{3RD\ COAST} * (3.0\ HRS)$

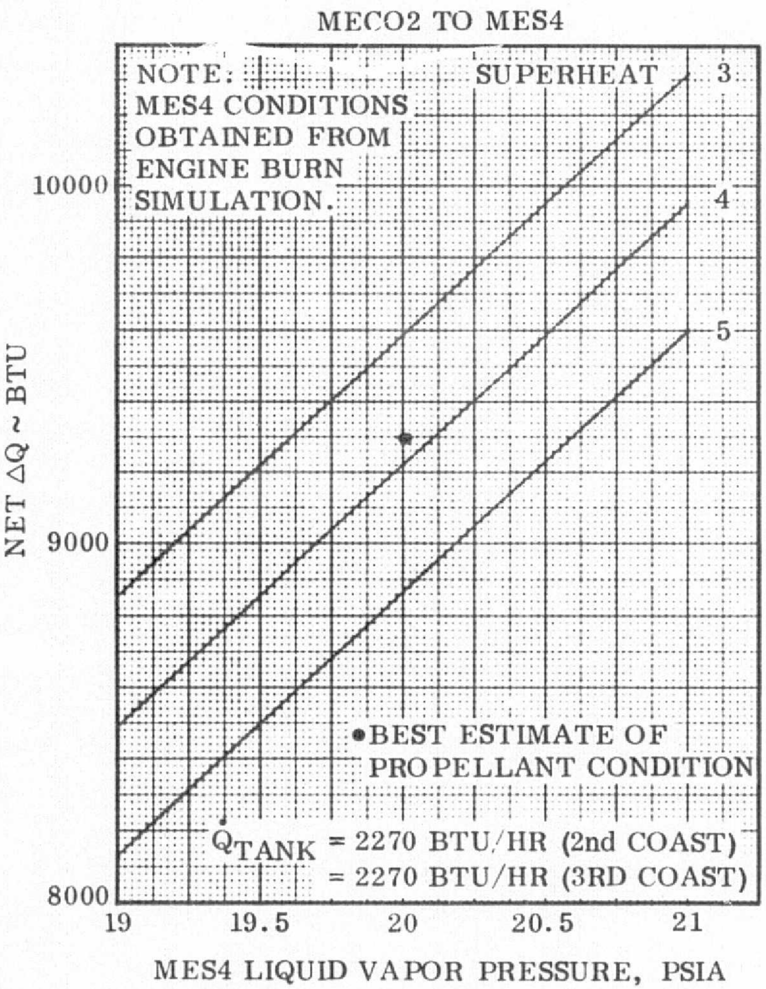
MECO 2 TO PRE-PROGRAMMED VENT CONDITIONS

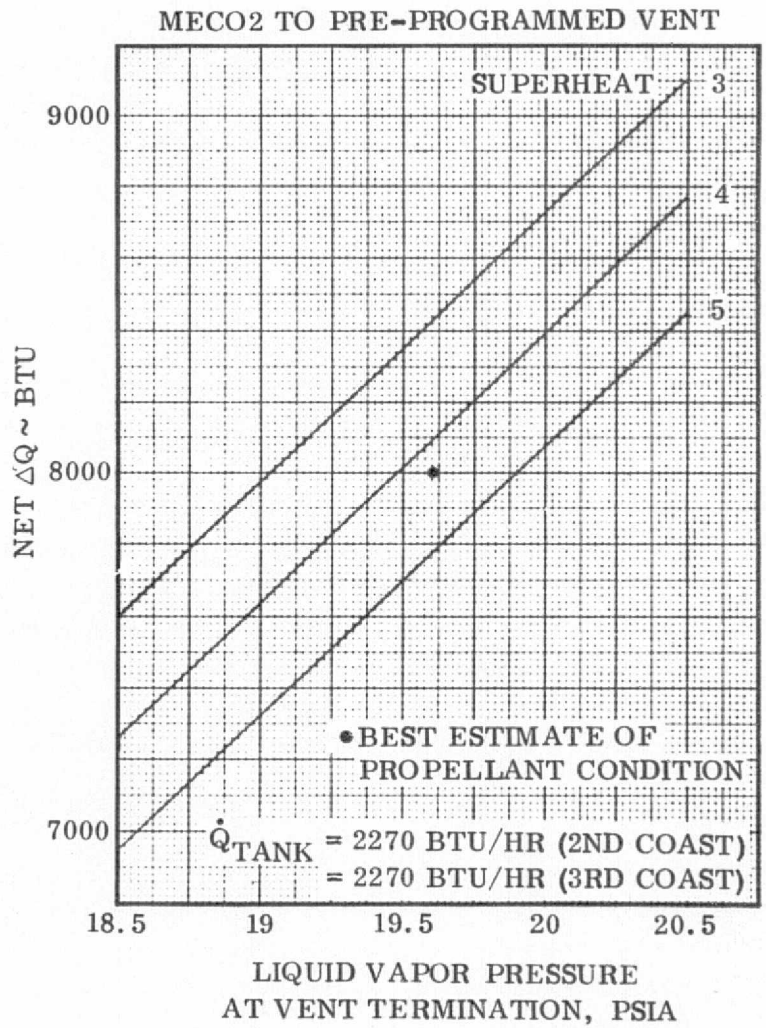
- $\Delta Q_{TANK} = \dot{Q}_{2ND\ COAST} * (1.0\ HRS) + \dot{Q}_{3RD\ COAST} * (2.44\ HRS)$

CALCULATED TANK HEATING RATES

- $\dot{Q}_{2ND\ COAST} = 2270$ BTU/HR
- $\dot{Q}_{3RD\ COAST} = 2270$ BTU/HR

NET HEAT INPUT TO LH_2 TANK VERSUS LIQUID VAPOR PRESSURE





SUMMARY OF LH_2 TANK THERMODYNAMIC CONDITIONS FROM MECO2 TO MECO4

- NET HEAT INPUT RATES OF 2270 BTU/HR ARE EMPLOYED TO DETERMINE INTERMEDIATE STATE CONDITIONS.
- TABULATED INTERMEDIATE STATE CONDITIONS ARE OBTAINED FROM ENERGY BALANCE.

CONCLUSIONS

- HELIUM PURGE CONTRIBUTION TO PROPELLANT TANK STATE WAS MINIMAL.
- INTERMEDIATE BULKHEAD HEAT TRANSFER RATE $\approx$ 1000 BTU/HR.
- LH_2 NEAR SATURATION THROUGHOUT COAST PERIODS.
- PRESSURANT HELIUM RESPONSIBLE FOR ULLAGE TEMPERATURE STRATIFICATION DURING 3RD COAST AND FOURTH MAIN ENGINE FIRING. ABOUT 17.2 LB. OF GH_2 AND HELIUM AT 74°R TEMPERATURE RESIDED AT THE FORWARD END OF THE TANK.
- H_2O_2 MOTOR FIRINGS RESULTED IN ΔP DECAYS OF UP TO 0.14 PSID, BUT DID NOT SIGNIFICANTLY COOL ULLAGE.

TC-5 APPLICATION

- 5-1/4 HOUR COAST PRESSURE RISE RATE WILL BE SIMILAR TO THE TC-2 3RD COAST PRESSURE RISE RATE.
- SIXTH COAST PRESSURE RISE RATE WILL BE TWO TIMES GREATER THAN FOR 5-1/4 HOUR COAST BECAUSE OF REDUCED LH_2 MASS.

TC-2 MISSION LH_2 TANK THERMODYNAMIC CONDITIONS

	MECO2	PRE-MES3	MES3	MECO3	PRE-PROG VENT	END VENT	PRE-MES4	MES4	MECO4	POST MECO4
TANK PRESSURE, PSIA	14.11	15.93	19.19	18.28	20.30	19.88	21.01	21.28	19.10	19.34
HYDROGEN PRESSURE, PSIA	13.98	15.80	18.84	17.94	19.96	19.54	20.67	21.76	18.68	18.82
HELIUM PRESSURE, PSIA	0.13	0.13	0.35	0.34	0.34	0.34	0.34	0.52	0.52	0.52
LIQUID PRESSURE, PSIA	14.23	15.55	15.55	15.55	19.83	19.60	20.00	20.00	19.10	18.8
LIQUID MASS, LB	1131.2	1126.3	1078.3	966.0	949.8	947.9	940.30	875.3	329.9	323.6
VAPOR MASS, LB.	81.30	86.20	86.20	86.20	101.43	100.76	108.4	108.4	110.1	110.4
HELIUM MASS, LB.	1.285	1.335	3.440	3.440	3.560	3.473	3.504	4.601	4.602	4.602
VAPOR TEMPERATURE, °R	36.3	38.4	46.0	44.7	43.1	42.6	42.5	45	42.4	42.6
VAPOR SUPERHEAT, °R	0.08	1.5	8	7	4.7	4.3	3.8	6.0	4.3	4.5
LH_2 EXPULSION, LB.		0	48	112.3	1	0	0	65	543.6	6
VAPOR VENT, LB.		0	0	0	0	2.51	0	0	0	0
NET HEAT RATE TO TANK, BTU/HR	2270									

TC-2 POST HELIOS EXPERIMENT DATA REVIEW

THERMAL AND HEAT TRANSFER

- PRELAUNCH THERMAL CONTROL BY GAS CONDITIONING AND PURGING
- PRELAUNCH TANK HEATING
- ASCENT THERMAL ENVIRONMENT AND RESPONSE
- SPACE AND VEHICLE INDUCED ENVIRONMENT
- FORWARD BULKHEAD MULTILAYER INSULATION
  - THERMAL RESPONSE AND PERFORMANCE
- THREE-LAYER SHIELDING
  - THERMAL RESPONSE AND PERFORMANCE
- TITANIUM STUB ADAPTER AND GROUND PLANE/SHIELD
  - THERMAL RESPONSE AND PERFORMANCE
- WIRING MODULE STRUCTURE/TYPICAL PENETRATION
  - THERMAL RESPONSE AND PERFORMANCE
- LH_2 TANK FLIGHT HEAT RATES

THERMAL AND HEAT TRANSFER

- LO_2 TANK SHIELD INSULATION KIT
  - — THERMAL RESPONSE AND LO_2 TANK FLIGHT HEAT RATES
- INTERMEDIATE BULKHEAD PERFORMANCE FROM PROPELLANT ENERGY BALANCES
- TANK VENT SYSTEMS
  - — THERMAL RESPONSE
- ELECTRONIC EQUIPMENT
  - — THERMAL RESPONSE AND PERFORMANCE
- HYDRAULIC SYSTEM
  - — THERMAL RESPONSE AND PERFORMANCE
- H_2O_2 SYSTEM
  - — THERMAL RESPONSE AND PERFORMANCE
- H_2O_2 SYSTEM EXHAUST IMPINGEMENT HEATING ENVIRONMENT
- MAIN PROPULSION SYSTEM
  - — THERMAL RESPONSE AND PERFORMANCE
- THERMAL CONTROL SUMMARY

THERMAL AND HEAT TRANSFER

- PRELAUNCH THERMAL CONTROL BY GAS CONDITIONING AND PURGING
- PRELAUNCH TANK HEATING
- ASCENT THERMAL ENVIRONMENT AND RESPONSE
- SPACE AND VEHICLE INDUCED ENVIRONMENT
- FORWARD BULKHEAD MULTILAYER INSULATION
  - — THERMAL RESPONSE AND PERFORMANCE
- THREE-LAYER SHIELDING
  - — THERMAL RESPONSE AND PERFORMANCE
- TITANIUM STUB ADAPTER AND GROUND PLANE/SHIELD
  - — THERMAL RESPONSE AND PERFORMANCE
- WIRING MODULE STRUCTURE/TYPICAL PENETRATION
  - — THERMAL RESPONSE AND PERFORMANCE
- LH_2 TANK FLIGHT HEAT RATES

CENTAUR D-1T/PAYLOAD/SHROUD MAJOR THERMAL PROTECTION AND INSULATION SYSTEMS

GENERAL DYNAMICS
Convair Aerospace Division

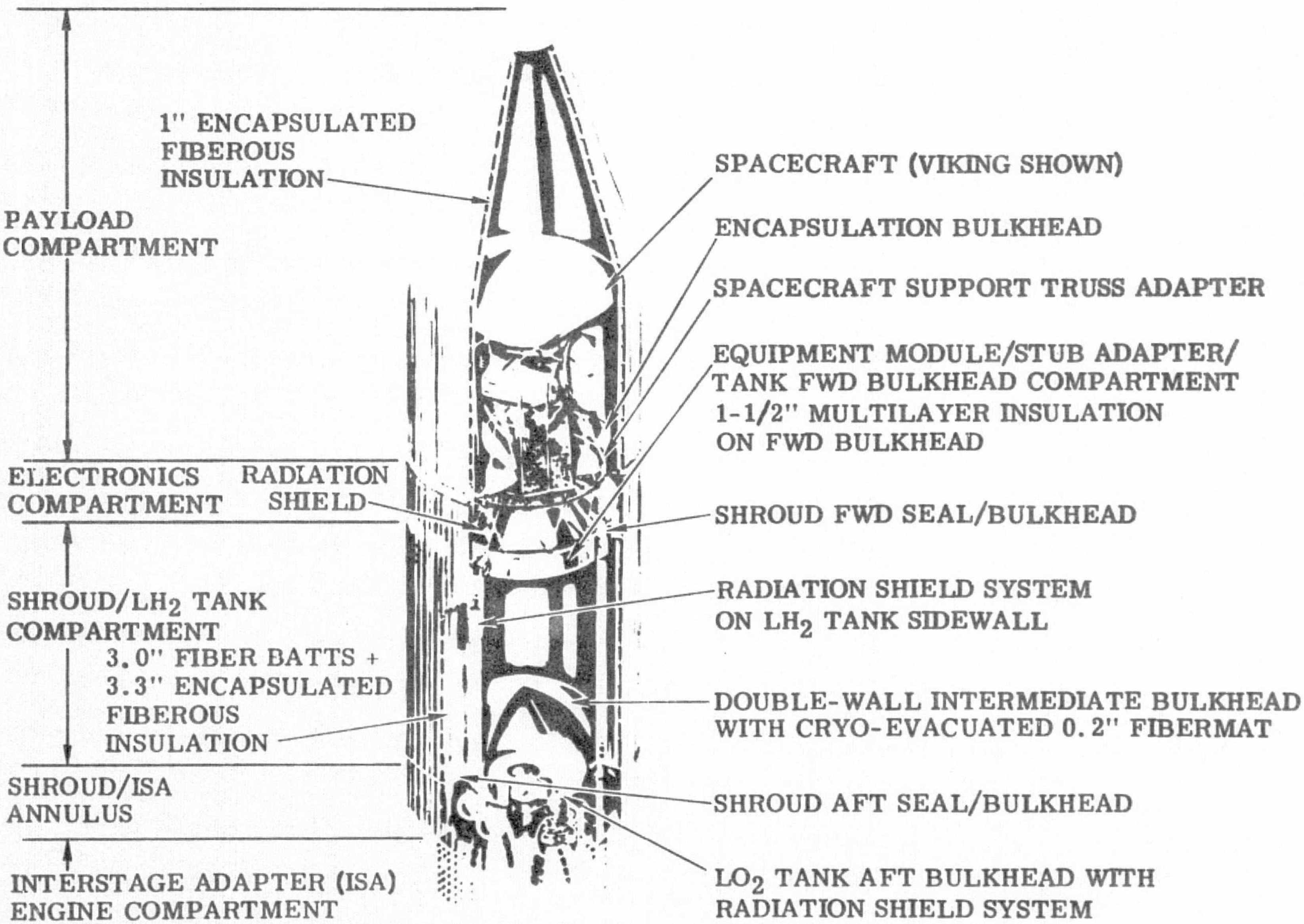


FIGURE 1-1

PRELAUNCH GAS CONDITIONING CONTROL OF EQUIPMENT ENVIRONMENT

GENERAL DYNAMICS
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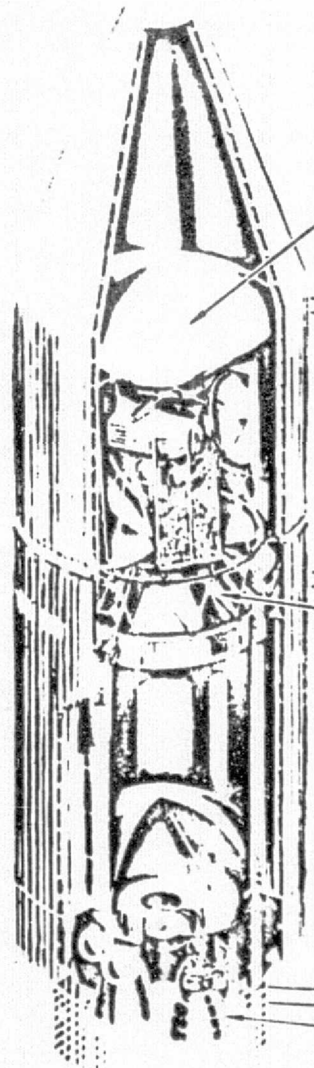


THERMAL CONDITIONING CRITERIA

PAYLOAD COMPARTMENT

HELIOS:

INLET TO COMPARTMENT	72^{+9}_{-13} °F
FLOW RATE	≥50 LB/MIN.
DEW POINT	52°F MAX.
SPACECRAFT HEAT	850 BTU/HR MAX.
SHROUD HEAT LOAD FROM AMBIENT	7000 BTU/HR MAX.

CENTAUR ELECTRONICS COMPARTMENT

EQUIPMENT TEMPS	40 - 100°F
DEW POINT	45°F MAX.
SHROUD HEAT LOAD FROM AMBIENT	13, 500 BTU/HR

MAKE-UP HEAT LOST TO CRYO-SINKS
PRESSURIZE AGAINST WIND INFLOW

INTERSTAGE ADAPTER/ENGINE COMPARTMENT

EQUIPMENT TEMPS	50 - 90 F
DEW POINT	45 F MAX.

MAKE-UP HEAT LOST TO CRYO-SYSTEMS
PRESSURIZE AGAINST WIND INFLOW

GAS REQUIREMENTS

ALL COMPARTMENTS USE AIR/GN_2 PRIOR TO/AFTER CRYOTANKING

HELIOS PAYLOAD

DESIGN	TC-2 FLIGHT
120 ± 5 LB/MIN GN_2 72^{+9}_{-13} °F	120 LB/MIN 72°F 36.5°F DP MAX
90 ± 5 LB/MIN. GN_2 70^{+5}_{-0} °F	90 LB/MIN 72°F 35.5°F DP MAX
130 ± 5 LB/MIN. GN_2 118^{+7}_{-3} °F	130 LB/MIN 118°F 38°F DP MAX

FIGURE 2-1

PAYLOAD ENVIRONMENTAL CONTROL CONDITIONS

COMPARTMENT TEMPERATURE REQUIREMENT 72^{+9}_{-13} °F

DATA	TCD		LAUNCH	
AMBIENT TEMPERATURE		72°F		48°F
INLET TEMPERATURE COS5T		72°F		72°F
INSULATION INSIDE TEMPERATURES				
CA192T STATION 2816	71.5°F		67°F	
CA193T STATION 2696	68.5		65	
CA196T STATION 2672	75.0		70	
CA194T STATION 2664	71.0		64	
PAYLOAD AMBIENT TEMPERATURE				
CY 19T STATION 2511	71.5		68	
AVERAGE COMPARTMENT TEMPERATURE		71.5°F		66.8°F
COMPARTMENT GAS TEMPERATURE CHANGE		- 0.5°F		- 5.2°F

EQUIPMENT MODULE COMPARTMENT TEMPERATURE LOCATIONS

GENERAL DYNAMICS
Convair Aerospace Division

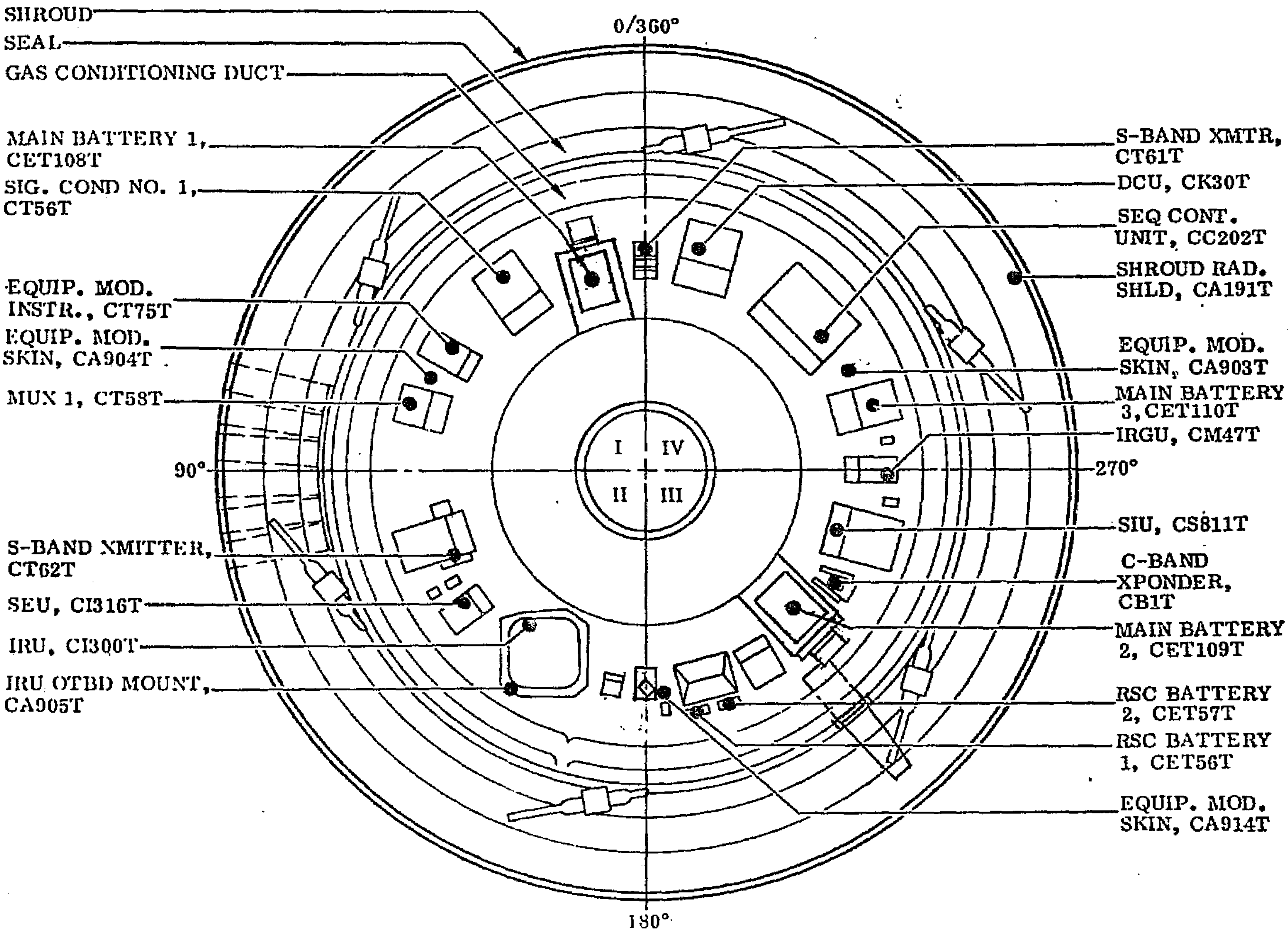


FIGURE 2-2

TABLE 2-II

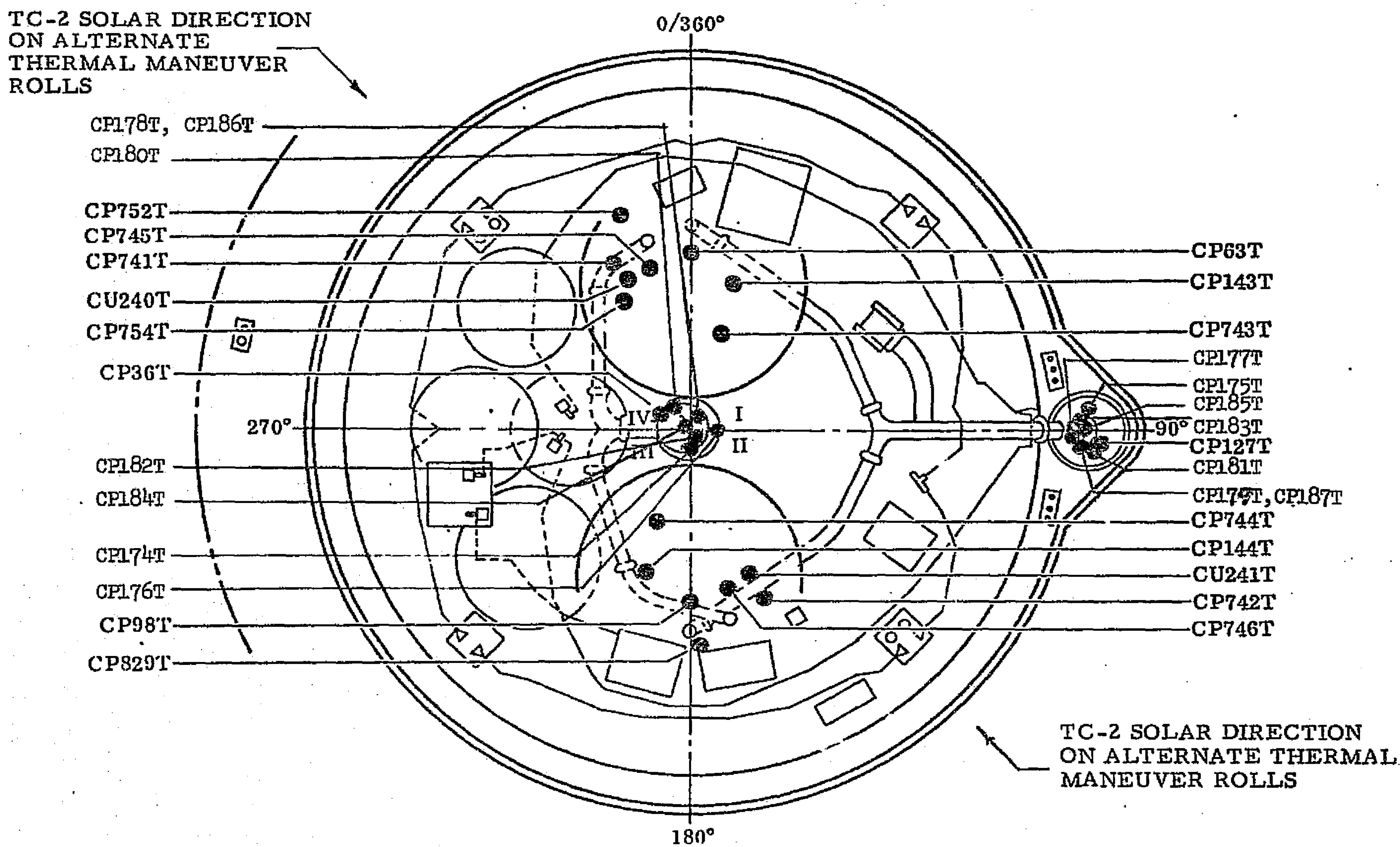
EQUIPMENT MODULE COMPARTMENT PRELAUNCH TEMPERATURE SURVEY

GENERAL DYNAMICS
Convair Aerospace Division

MEAS. NO.	COMPONENT	TEMPERATURE, °F PRIOR TO LH_2	TEMPERATURE, °F LIFTOFF	$\frac{dT}{d\tau}$, °F/HR @ LIFTOFF	ADJUSTED STEADY-STATE TEMP, °F	LH_2 TANKING ΔT, °F
CA905T	IRU OUTBOARD MOUNT	90	81	0		-9
CB1T	C-BAND XPONDER	77	69	0		-8
CC202T	SCU HOUSING WEB	78	71	-2	69	-9
CI300T	IRU SKIN INTERNAL	90	82	-1	81	-9
CI316T	SEU INTERNAL	80	72	-2	71	-9
CK30T	DCU SKIN	91	86	-2	85	-6
CM47T	IRGU GYRO BLOCK	93	88	-3	86	-7
CS811T	SIU SKIN	80	75	-2	74	-6
CT56T	SIG CONDITIONER NO. 1	78	72	0		-6
CT58T	EQUIP MODULE MUX 1	78	71	-3	69	-9
CT61T	S-BAND XMTR INT-PCM	91	86	0		-5
CT62T	S-BAND XMTR INT-FM	90	82	0		-8
CT75T	EQU MOD INSTR BOX	79	74	-2	72	-7
	AVERAGE ΔT					$-7.54^{-1.46}_{+2.54}$
COMPUTED COMPARTMENT GAS		68.59	61.05			
COMPARTMENT BOUNDARY CONDITIONS						
COS8T	CEM GAS INLET	71.5	72	0		0
CY119	S/C COMP AMB AT ADPT	74	68	0		-6
CA901T	P/L ADAPTER	73	68	0		-5
CA903T	EQUIP MODULE SKIN Q4	71	42	0		-29
CA904T	EQUIP MODULE SKIN Q1	71	41	0		-30
CA914T	EQUIP MODULE SKIN +Z	72	54	0		-18
CA191T	RAD SHLD ST 2485/300	75	71	0		-4

ENERGY BALANCE COMPUTED HEAT RATE FROM MODULE COMPARTMENT TO LH_2 TANK BOUNDARIES AT LIFTOFF = 25,190 BTU/HR.

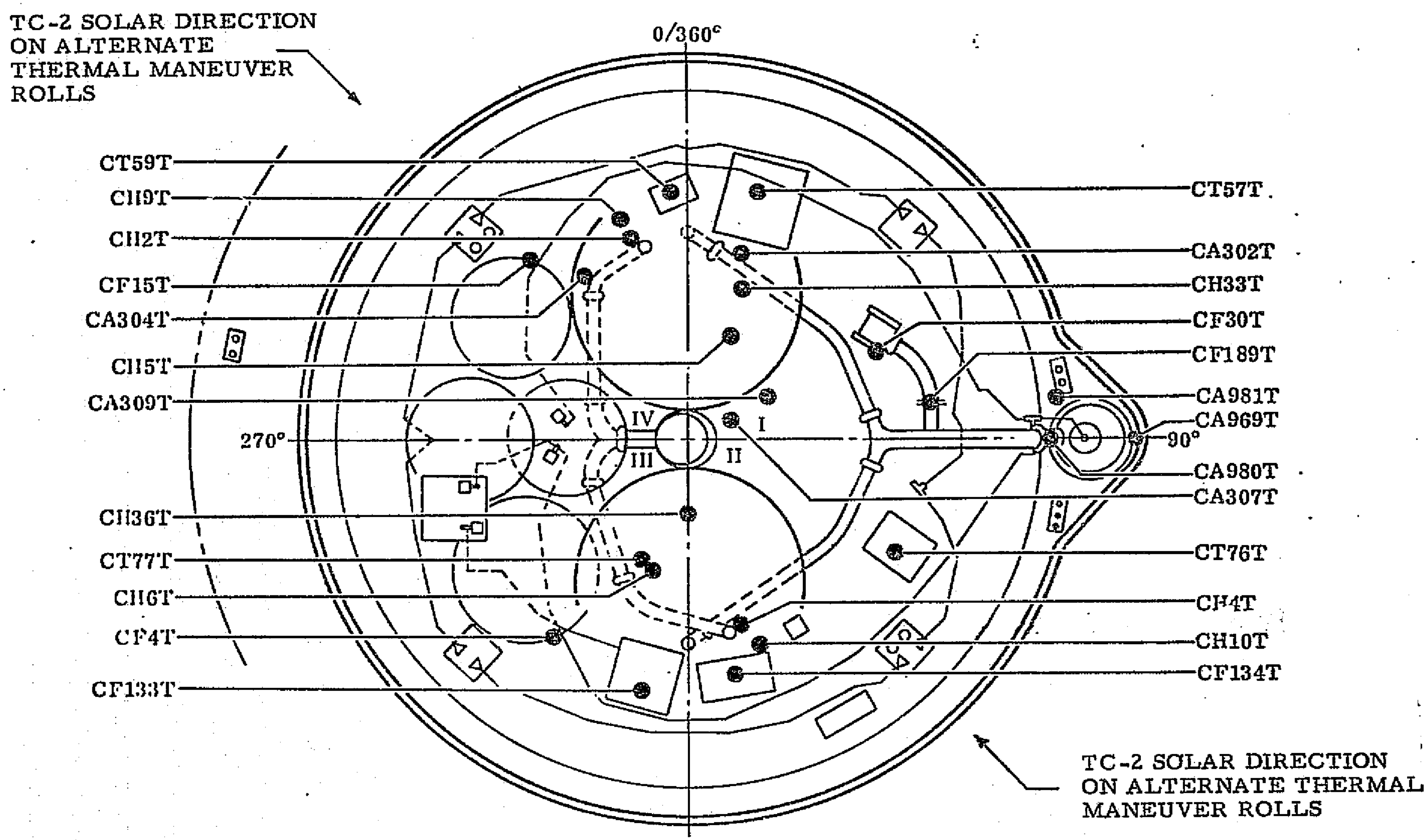
MAIN PROPULSION ENVIRONMENTAL TEMPERATURE LOCATIONS



AFT BULKHEAD — VIEW LOOKING FORWARD

FIGURE 2-3

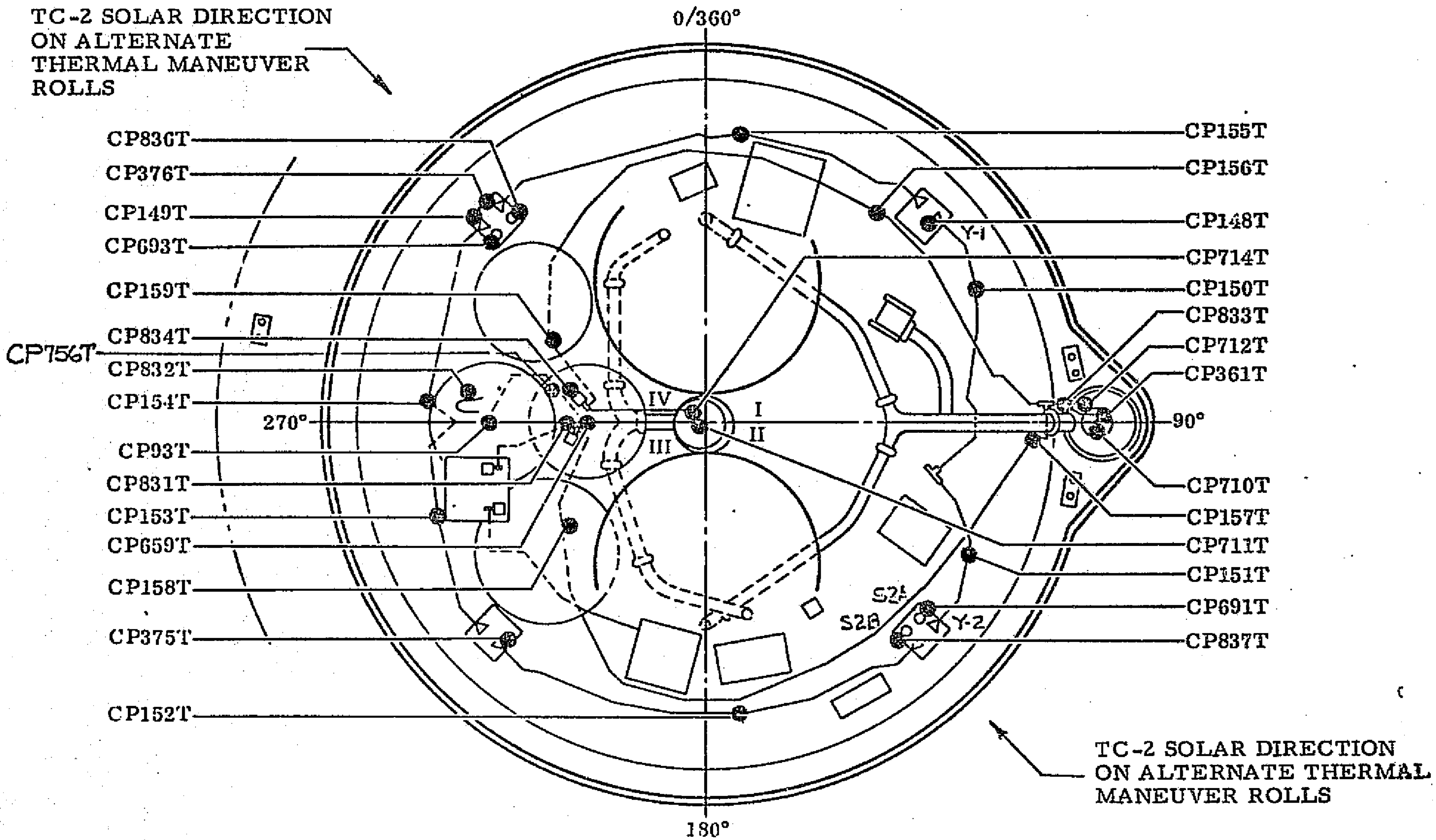
SHIELDING, HYDRAULIC, PNEUMATIC ENVIRONMENTAL TEMPERATURE LOCATIONS



AFT BULKHEAD — VIEW LOOKING FORWARD

FIGURE 2-4

H_2O_2 SYSTEM TEMPERATURE LOCATIONS



AFT BULKHEAD — VIEW LOOKING FORWARD

FIGURE 2-5

TABLE 2-V

INTERSTAGE ADAPTER PRELAUNCH TEMPERATURE SURVEY
CENTRAL ZONE NON-CRYOGENIC TEMPERATURES

MEAS. NO.	COMPONENT	* LO_2 °F	* LH_2 °F	ΔT LO_2 °F	* LHe °F	ΔT LH_2 °F	LIFT-OFF °F	$\frac{dT}{d\tau}$ @ LIFT-OFF °F/HR	TEMP. @ LHe † °F	ΔT LHe °F
CA309T	LO_2 AFT BLKHD OUTER SHIELD	110	54	CRYO	48	-6	35	0	—	-13
CA307T	LO_2 SUMP OUTER RAD. SHIELD	107	69	CRYO	67	-2	48	0	—	-19
CH36T	C-2 PITCH ACTUATOR BODY	106	96	-SLOPE	86	-SLOPE	73	-13	NOT PROJ	-
CP36T	LO_2 B.P. TURBINE BEARING	107	95	-SLOPE	88	—	72	-19	68	-20
CP714T	LO_2 B.P. INLET LINE	102	89	-13	86	-3	66	0	—	-20
CP711T	LO_2 B.P. ORIFICE HOLDER	101	86	-15	83	-3	65	-17	61	-22
CP756T	H_2O_2 MANIFOLD LINE	(98)‡ 110	95	-SLOPE	93	—	79	-7	77	-16

*START

†PROJECTED STEADY-STATE CONDITIONS.

‡TEMPERATURES IN ( ) ARE ADJUSTED TO ELIMINATE HEATER EFFECT.

TABLE 2-V (continued)

INTERSTAGE ADAPTER PRELAUNCH TEMPERATURE SURVEY
CENTRAL ZONE NON-CRYOGENIC TEMPERATURES

MEAS. NO.	COMPONENT	* LO_2 °F	* LH_2 °F	ΔT LO_2 °F	* LHe °F	ΔT LH_2 °F	LIFT-OFF °F	$\frac{dT}{d\tau}$ @ LIFT-OFF °F/HR	TEMP. @ LHe† °F	ΔT LHe °F
CP174T	LO_2 B.P. SHAFT HOUSING	96	0	CRYO	+ 3	SPIN -SLOPE	- 7	0	-	-10
CP176T	LO_2 B.P. GEAR CASE	108	90	-SLOPE	81	SPIN -SLOPE	66	-13	62	-19
CP178T	LO_2 B.P. DECOMP. CHAMBER	(106) 143	133	-SLOPE	128	SPIN	110	-13	106	-22
CP180T	LO_2 B.P. TURBINE HSG OUTBOARD	97	87	-SLOPE	80	-	65	-13	61	-19
CP182T	LO_2 B.P. TURBINE HSG AFT	100	85	-15	77	- 8	65	0	-	-12 TC
CP184T	LO_2 B.P. LOCK-ROTOR BOSS	97	85	-SLOPE	80	-	65	-10	63	-17
CP186T	LO_2 B.P. DECOMP CHAMBER TC	(104) 141	126	-SLOPE	122	-	105	-13	101	-21 TC
	AVERAGE	(102.8)‡		-14.3		-4.4				-17.7

‡ TEMPERATURES IN ( ) ARE ADJUSTED TO ELIMINATE HEATER EFFECT.

TABLE 2-X

SUMMARY OF INTERSTAGE ADAPTER AND ISA/SHROUD ANNULUS INDICATED COMPARTMENT AVERAGE GAS TEMPERATURE

ZONE	START LO_2		LO_2 TANKING			LH_2 TANKING			LONG DURATION LHe CHILLDOWN		
	NO. OF MEAS'S	TEMP °F	NO. OF MEAS'S	ΔT °F	TEMP °F	NO. OF MEAS'S	ΔT °F	TEMP °F	NO. OF MEAS'S	ΔT °F	TEMP °F
ISA CENTRAL	14	102.8	3	-14.3	88.5	5	- 4.4	84.1	13	-17.7	66.4
C-1 ENGINE	11	97.9	9	-11.3	86.6	6	- 5.3	81.3	8	-22.0	59.3
C-2 ENGINE	10	99.0	8	-13.6	85.4	7	- 4.7	80.7	9	-26.7	54.0
ISA PERIPHERY	19	101.5	15	-19.3	82.5	15	- 3.9	78.3	19	-14.7	63.6
TOTAL ISA	54	100.6	35	-15.5	85.1	33	- 4.4	80.7	49	-18.9	61.8
LH_2 BOOST PUMP VICINITY	12	102.9	6	-15.3	87.6	6	- 4.5	83.1	12	-11.3	71.8

TABLE 2-XI

SUMMARY OF PRELAUNCH CRYOGEN HEAT RATES FROM AFT COMPARTMENTS ENERGY BALANCE

HEAT RATE FROM		TEMPERATURE, °F			OVERALL COEFFICIENT (UA)	HEAT RATE AT LIFTOFF
COMPARTMENT	TO:	COMP'T	SINK	ΔT	BTU/HR-°F	BTU/HR
ISA	LO_2	61.8	-284	345.8	94.3	32,610
ANNULUS (ISA CONDUCTION)	LO_2	53.0	-284	337.0	42.4	14,290
ISA	LH_2	61.8	-420	481.8	14.5	6,990
ANNULUS	LH_2 SUMP	71.8	-420	491.8	1.8	890
ANNULUS	TANK/SHROUD He	53.0	-350	403.0	50.4	20,310
ISA	LHe CHILL	61.8	-440	501.8	102.6	51,480
ISA	TITAN SKIRT	61.8	65	- 3.2	135.0	- 430
ISA	AMBIENT	61.8	48.0	13.8	604.0	8,340
ISA	ANNULUS	61.8	53	8.8	535.0	4,710
ANNULUS	AMBIENT	53.0	48.0	5.0	457.0	2,290
ELECT/HEATERS	ISA	——	61.8	——	——	1,160
ELECT/HEATERS	ANNULUS	——	71.8	——	——	140

TANK SECTION INSTRUMENTATION CONFIGURATION

GENERAL DYNAMICS
Convair Aerospace Division

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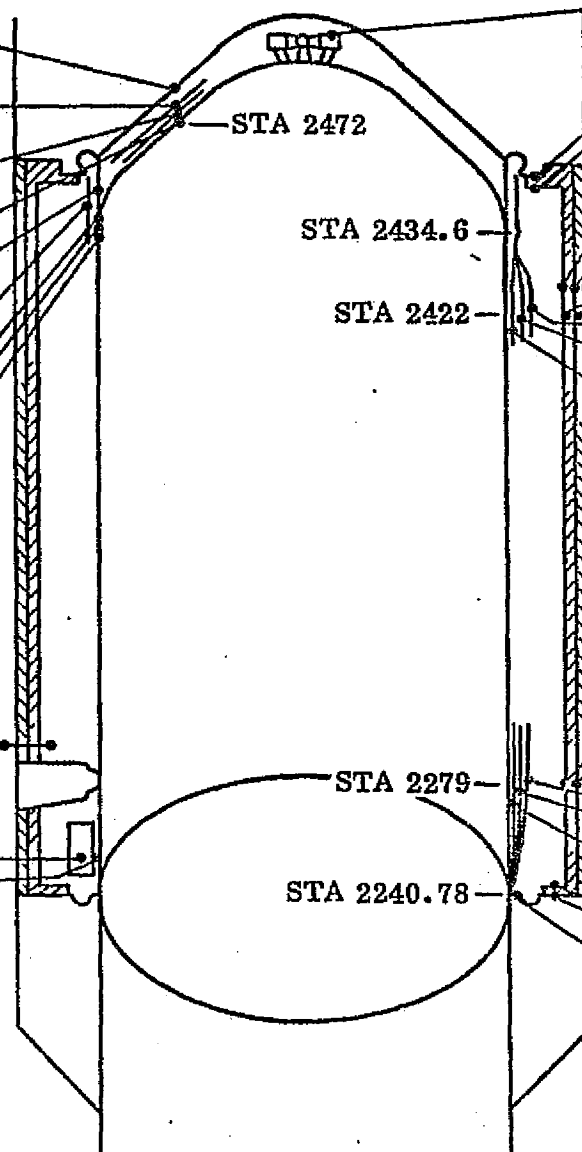
LAUNCH TEMPERATURES – °F

TC-2	TC-1	
44	38	CA903T/300°
41	40	CA904T/66°
53	49	CA914T/186°
-62	-70	CA909T/186°
-56	-62	CA910T/306°
-79	-65	CA913T/60°
-217	-220	CA911T/306°
-216	-190	CA912T/60°
-416	-417	CA906T/166°
-416	-416	CA907T/186°
-416	-418	CA908T/306°
-53	-50	CA979T/180°
-64	-40	CA972T/180°
-70	-85	CA973T/100°
-35	-40	CA974T/0°
-53	-40	CA975T/270°
-145	-155	CA978T/180°
-173	-160	CA977T/180°
-256	-270	CA976T/180°

.165/.173 PSID CAS893P VS. REDLINE
.045 PSID MIN FOR WINDS LESS
THAN 33 KNOTS. LAUNCH
WIND = 7/4 KNOTS FOR TC-1/e

TC-2	TC-1	
6	15	CA989T/90°
11	10	CA988T/90°



LAUNCH TEMPERATURES – °F

	TC-1	TC-2
CF31T/190°	-160	-134
CA197T/315°	15	16
CA204T/315°	-45	-47
CA206T/308°	-85	-40
CA208T/60°	-60	-59
CA207T/308°	10	-4
CA178T/315°	70	37
CA179T/60°	50	42
CA180T/128°	55	50
CA205T/308°	-105	-100
CA198T/308°	55	21
CA952T/293°	-135	-122
CA960T/69°	-145	-133
CA953T/293°	-255	-273
CA961T/69°	-250	-195
CA954T/293°	-295	-305
CA962T/69°	-300	-300
CA209T/308°	-340	-343
CA210T/308°	-110	-138
CA181T/308°	55	25
CA182T/68°	45	39
CA183T/128°	40	38
CA955T/293°	-345	-343
CA963T/203°	-360	-355
CA956T/293°	-370	-380
CA964T/203°	-385	-380
CA957T/293°	-405	-387
CA965T/203°	-410	-387
CA211T/300°	-355	-356
CA199T/308°	-55	-60
CA980T/90°	-180	-212
CA981T/82°	30	35

THERMAL AND HEAT TRANSFER

- PRELAUNCH THERMAL CONTROL BY GAS CONDITIONING AND PURGING
- PRELAUNCH TANK HEATING
- ASCENT THERMAL ENVIRONMENT AND RESPONSE
- SPACE AND VEHICLE INDUCED ENVIRONMENT
- FORWARD BULKHEAD MULTILAYER INSULATION
  - THERMAL RESPONSE AND PERFORMANCE
- THREE-LAYER SHIELDING
  - THERMAL RESPONSE AND PERFORMANCE
- TITANIUM STUB ADAPTER AND GROUND PLANE/SHIELD
  - THERMAL RESPONSE AND PERFORMANCE
- WIRING MODULE STRUCTURE/TYPICAL PENETRATION
  - THERMAL RESPONSE AND PERFORMANCE
- LH_2 TANK FLIGHT HEAT RATES

TABLE 3-I

LH2 BOIL-OFF TESTS DURING TCD

TEST NUMBER	1	2	3
PURGE RATE	HIGH	HIGH	HIGH
ULLAGE PRESSURE (PSIA)	21.00	20.86	21.14
ELAPSED TIME 57.63 FT^3 BOIL-OFF FROM 99.8% TO 95% (MINUTES)	22.93	23.925	23.91
LH_2 DENSITY (LB/FT^3)	4.30	4.30	4.30
HEAT OF VAPORIZATION (BTU/LB)	189.2	189.2	189.2
AVERAGE HEAT RATE TO LIQUID (BTU/HR)	123,000	117,900	118,000
Δ HEAT RATE TO FULL TANK (BTU/HR)	4,220	4,220	4,220
HEAT RATE TO FULL TANK LIQUID (BTU/HR)	127,220	122,120	122,220

AVERAGE HEAT RATE TO FULL TANK LIQUID (BTU/HR) = 123,850

TABLE 3-II

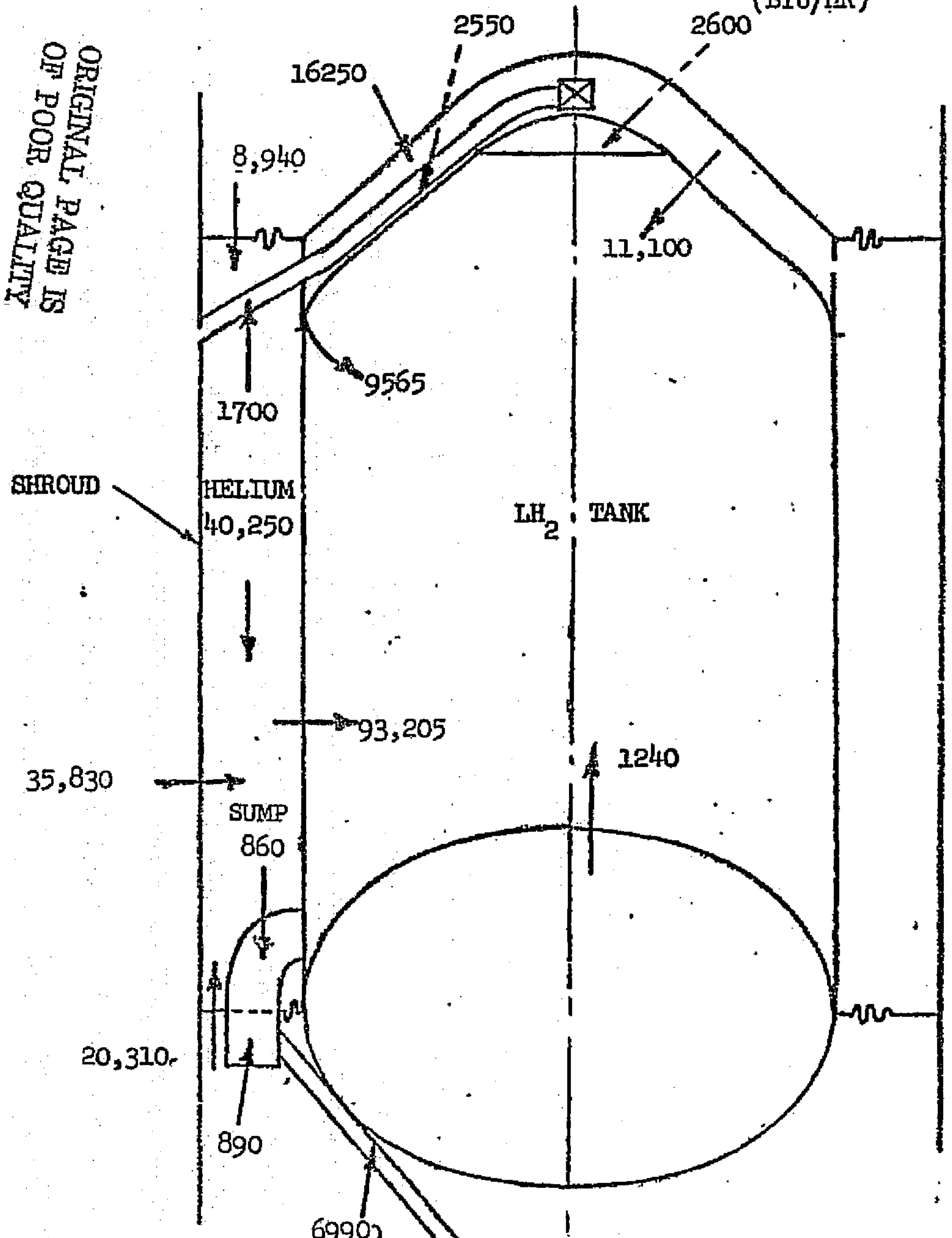
LO_2 BOIL-OFF TESTS DURING TCD

TEST NUMBER	1	2	3
SHROUD PURGE RATE	HIGH	HIGH	HIGH
ULLAGE PRESSURE (PSIA)	30.95	30.79	30.79
ELAPSED TIME FOR 1.64 FT^3 BOIL-OFF FROM 100.2% TO 99.8% (MINUTES)	8.74	12.075	12.055
LO_2 DENSITY (LB/FT^3)	69.0	69.0	69.0
HEAT OF VAPORIZATION (BTU/LB)	90.0	90.0	90.0
NET HEAT RATE TO LO_2 (BTU/HR) (W/O LHe CHILLDOWN)	71,300	51,600	51,700
AVERAGE HEAT RATE (BTU/HR) (LAST TWO TESTS ONLY)			51,650

HEAT RATE ADJUSTED FOR LHe CHILLDOWN AND LAUNCH TEMPERATURES * $= \left(\frac{521.8-176}{545-176}\right) \times 51,650 = 48,300$ BTU/HR

* LO_2 NET HEAT RATE NOT AFFECTED BY SMALL CHANGES IN LIQUID LEVEL SO NO ADJUSTMENT REQUIRED TO FULL TANK.

LH_2 TANK PRELAUNCH HEATING RATE BREAKDOWN
(BTU/HR)

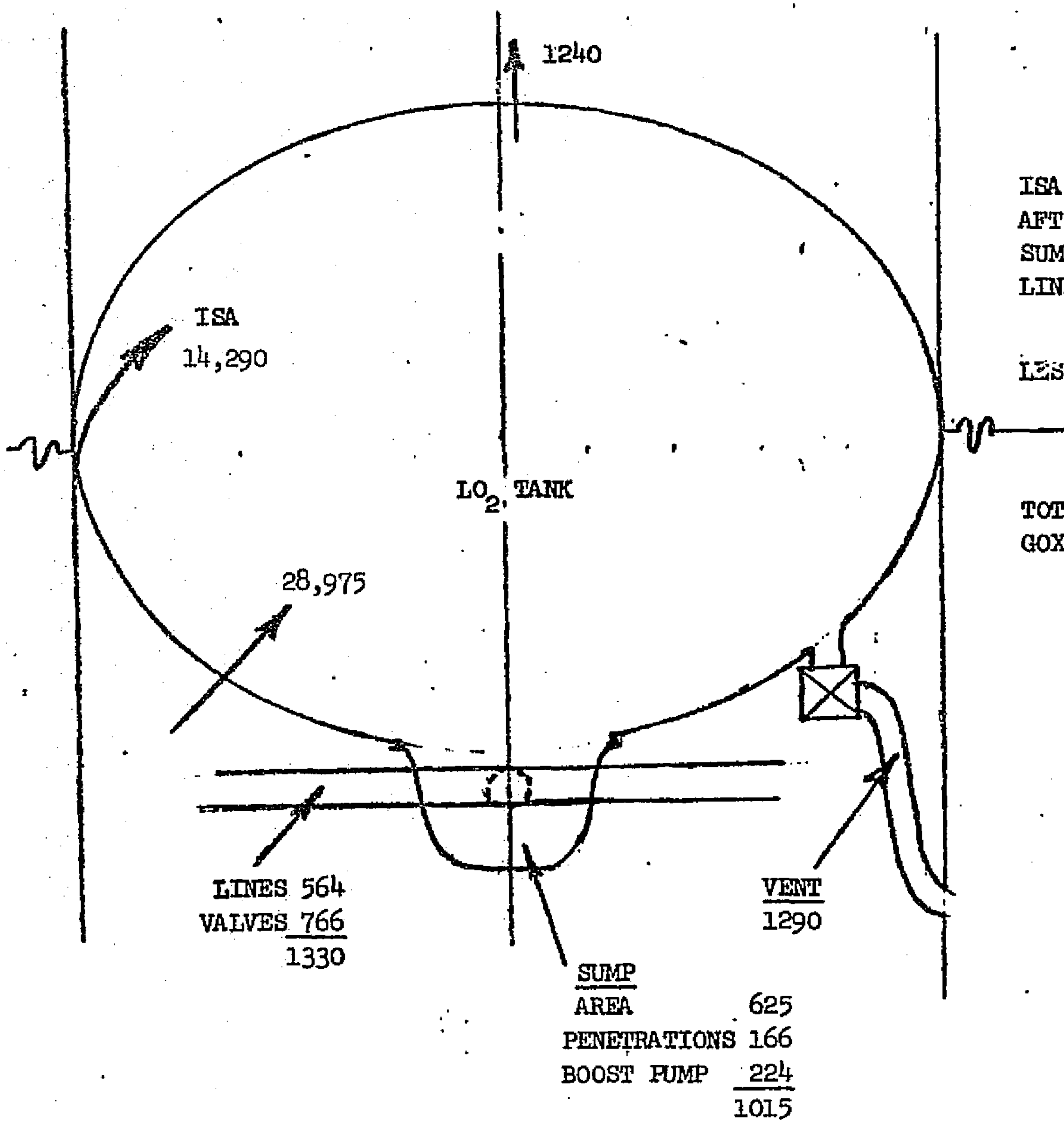


SUMMARY OF HEAT BALANCE

TANK HEATING		
LIQUID		
FWD BULKHEAD (AFT TO S/A MIDFRAME)		11,100
STUB ADAPTER (S/A)		9,565
SIDEWALL		93,205
SUMP FWD OF SEAL		860
SUMP AFT OF SEAL		890
LINES & MAIN VALVES		6,990
INTERMEDIATE BULKHEAD		1,240
	LH_2 TOTAL	123,850
ULLAGE		2,600
	TANK TOTAL	126,450
SHROUD HEATING		
FWD SEAL		8,940
AFT SEAL		20,310
HELIUM PURGE		40,250
SHROUD SIDE		35,830
	TOTAL	105,330
HEATING FROM SHROUD/TANK COMP'T TO TANK AND VENT		
STUB ADAPTER		9,565
SIDEWALL		93,205
SUMP		860
VENT DISCONNECT		1,700
	TOTAL	105,330

FIGURE 3-1

LO_2 TANK PRELAUNCH HEATING RATE BREAKDOWN
(BTU/HR)



SUMMARY OF HEAT BALANCE

ISA	14290
AFT BULKHEAD	28975
SUMP	1015
LINES & MAIN VALVES	1330
TOTAL LO_2	45610
LESS INTERMEDIATE BULKHEAD	-1240
NET LO_2 HEAT	44370
TOTAL LO_2	45610
GOX VENT	1290
TOTAL FROM GN_2	46900

FIGURE 3-2

THERMAL AND HEAT TRANSFER

- PRELAUNCH THERMAL CONTROL BY GAS CONDITIONING AND PURGING
- PRELAUNCH TANK HEATING
- ASCENT THERMAL ENVIRONMENT AND RESPONSE
- SPACE AND VEHICLE INDUCED ENVIRONMENT
- FORWARD BULKHEAD MULTILAYER INSULATION
  - — THERMAL RESPONSE AND PERFORMANCE
- THREE-LAYER SHIELDING
  - — THERMAL RESPONSE AND PERFORMANCE
- TITANIUM STUB ADAPTER AND GROUND PLANE/SHIELD
  - — THERMAL RESPONSE AND PERFORMANCE
- WIRING MODULE STRUCTURE/TYPICAL PENETRATION
  - — THERMAL RESPONSE AND PERFORMANCE
- LH_2 TANK FLIGHT HEAT RATES

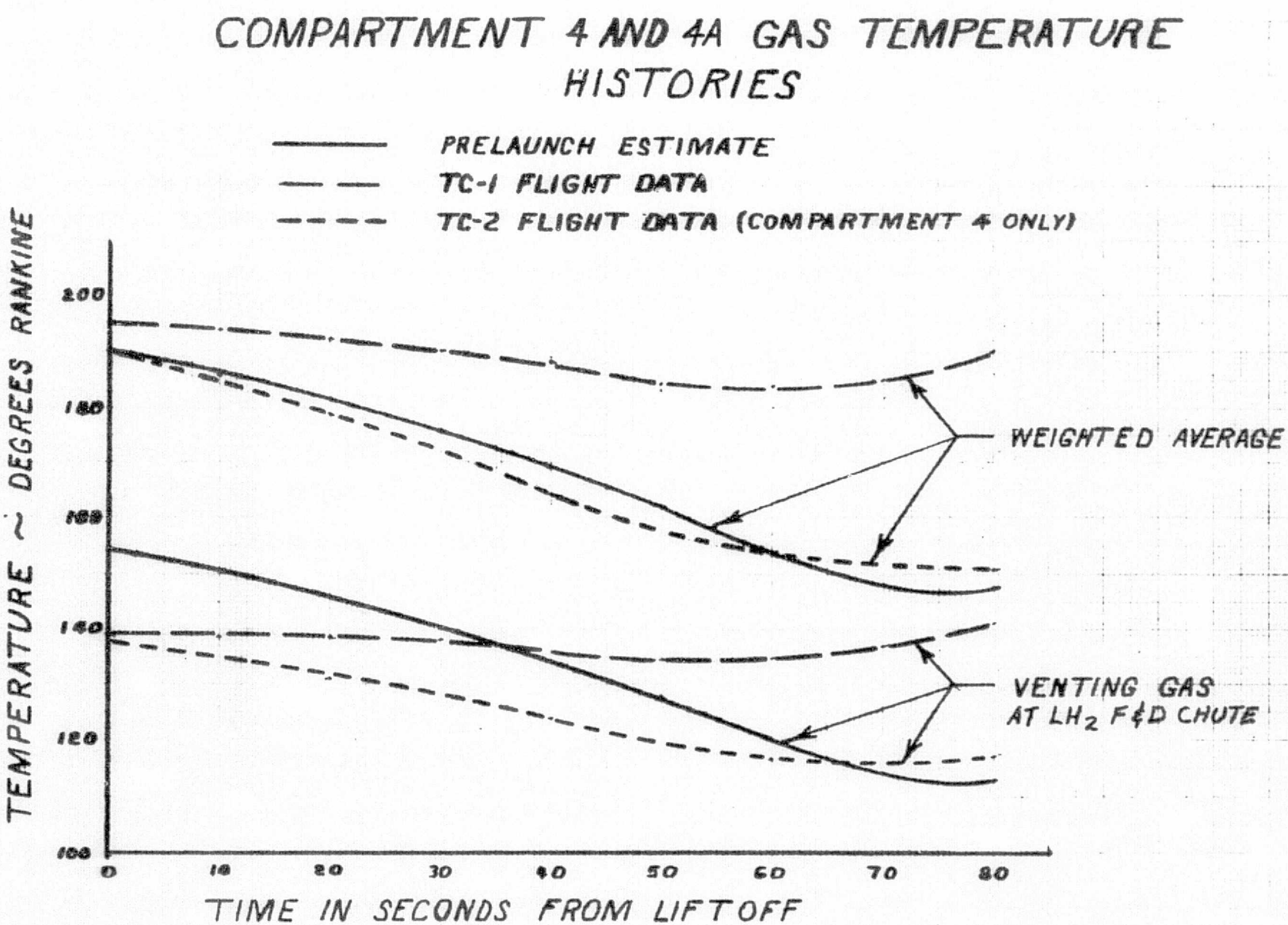
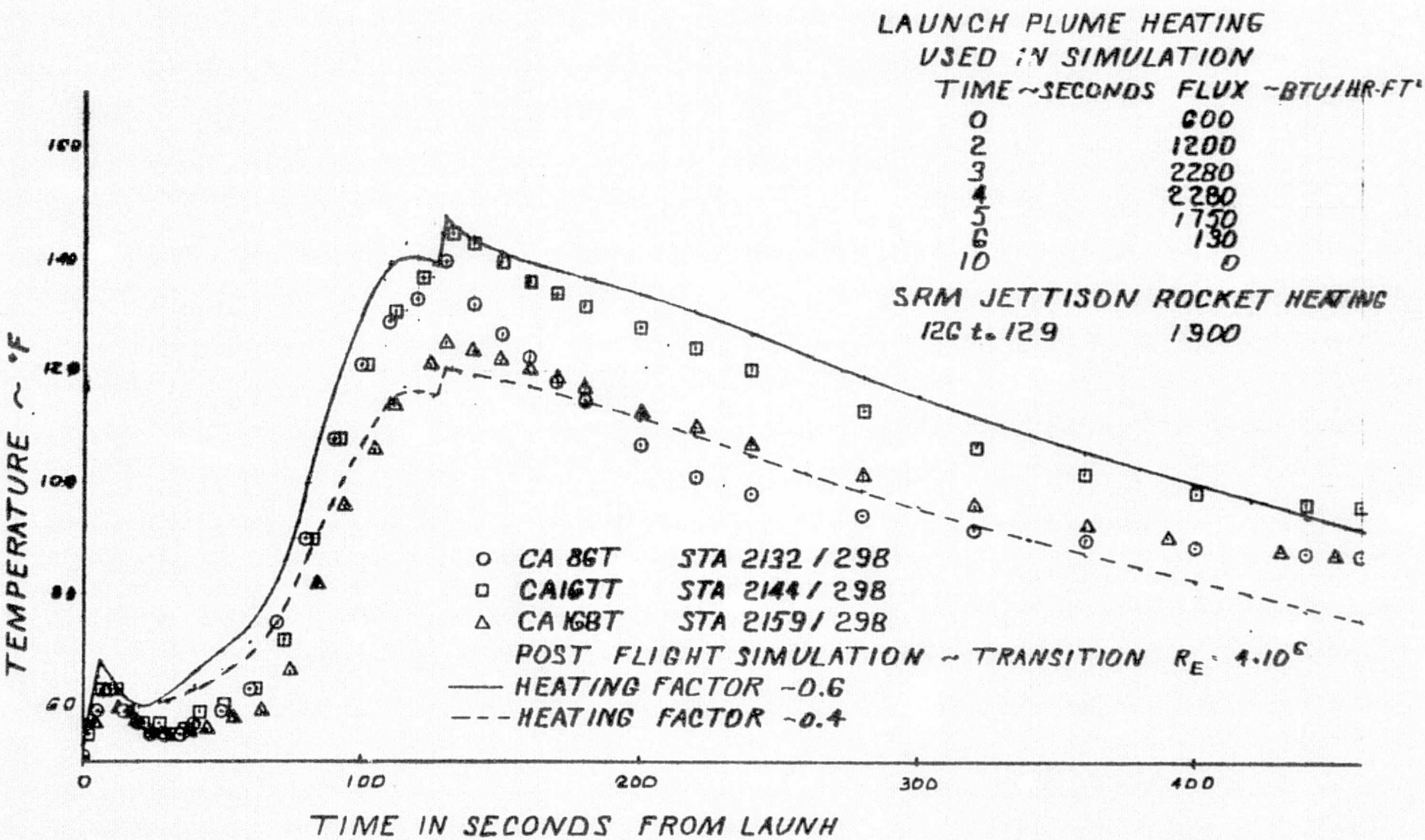

COMPARTMENT 4 AND 4A GAS TEMPERATURE HISTORIES
PRELAUNCH ESTIMATE
TC-1 FLIGHT DATA
TC-2 FLIGHT DATA (COMPARTMENT 4 ONLY)
TEMPERATURE ~ DEGREES RANKINE
200
180
160
140
120
100
0
10
20
30
40
50
60
70
80
WEIGHTED AVERAGE
VENTING GAS
AT LH_2 F&D CHUTE
TIME IN SECONDS FROM LIFTOFF

FIGURE 4-1

INTERSTAGE ADAPTER ASCENT HEATING



INDICATED RECIRCULATION AFT OF BOATTAIL

GENERAL DYNAMICS
Convair Aerospace Division

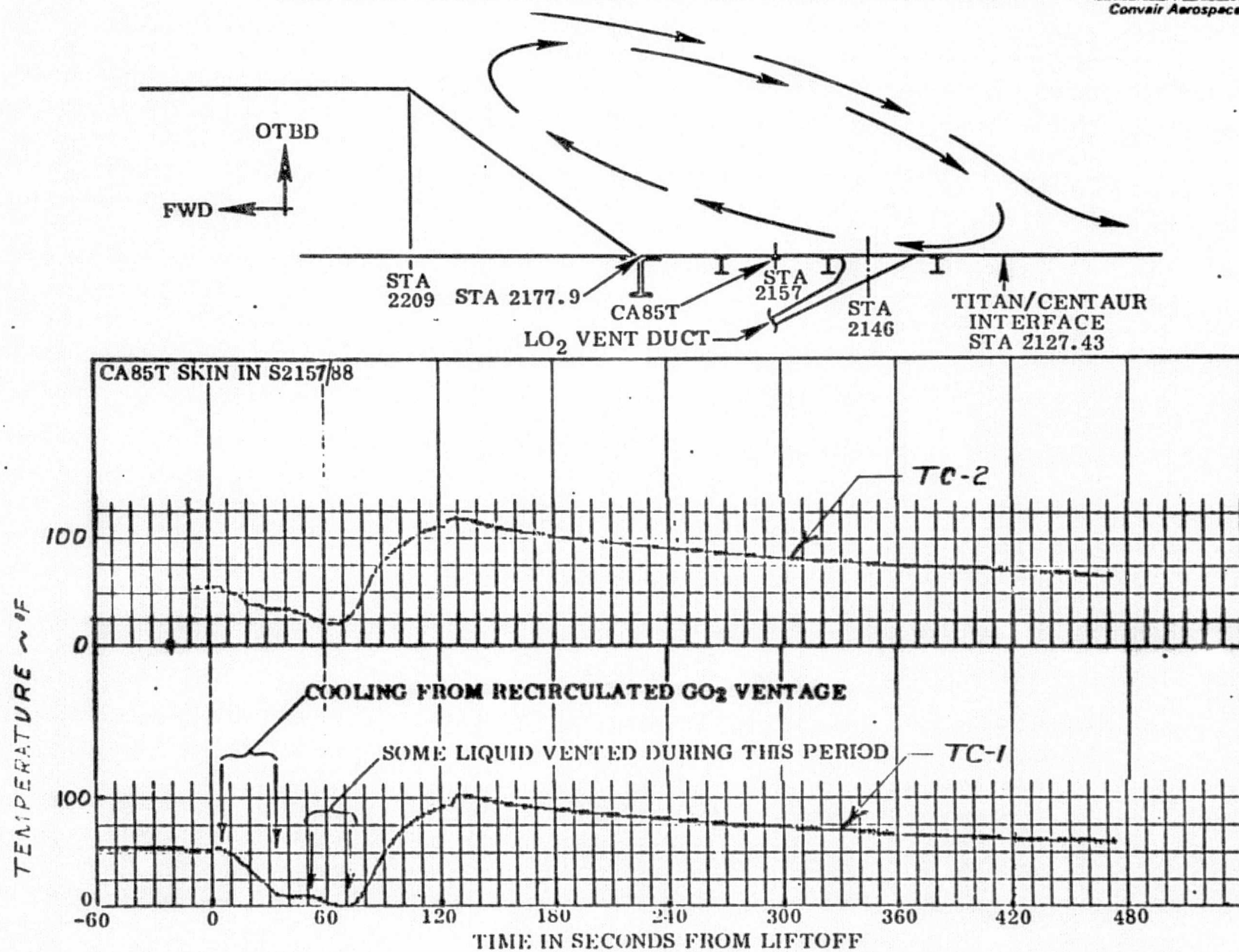


FIGURE 5-2

THERMAL AND HEAT TRANSFER

- PRELAUNCH THERMAL CONTROL BY GAS CONDITIONING AND PURGING
- PRELAUNCH TANK HEATING
- ASCENT THERMAL ENVIRONMENT AND RESPONSE
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- LH_2 TANK FLIGHT HEAT RATES

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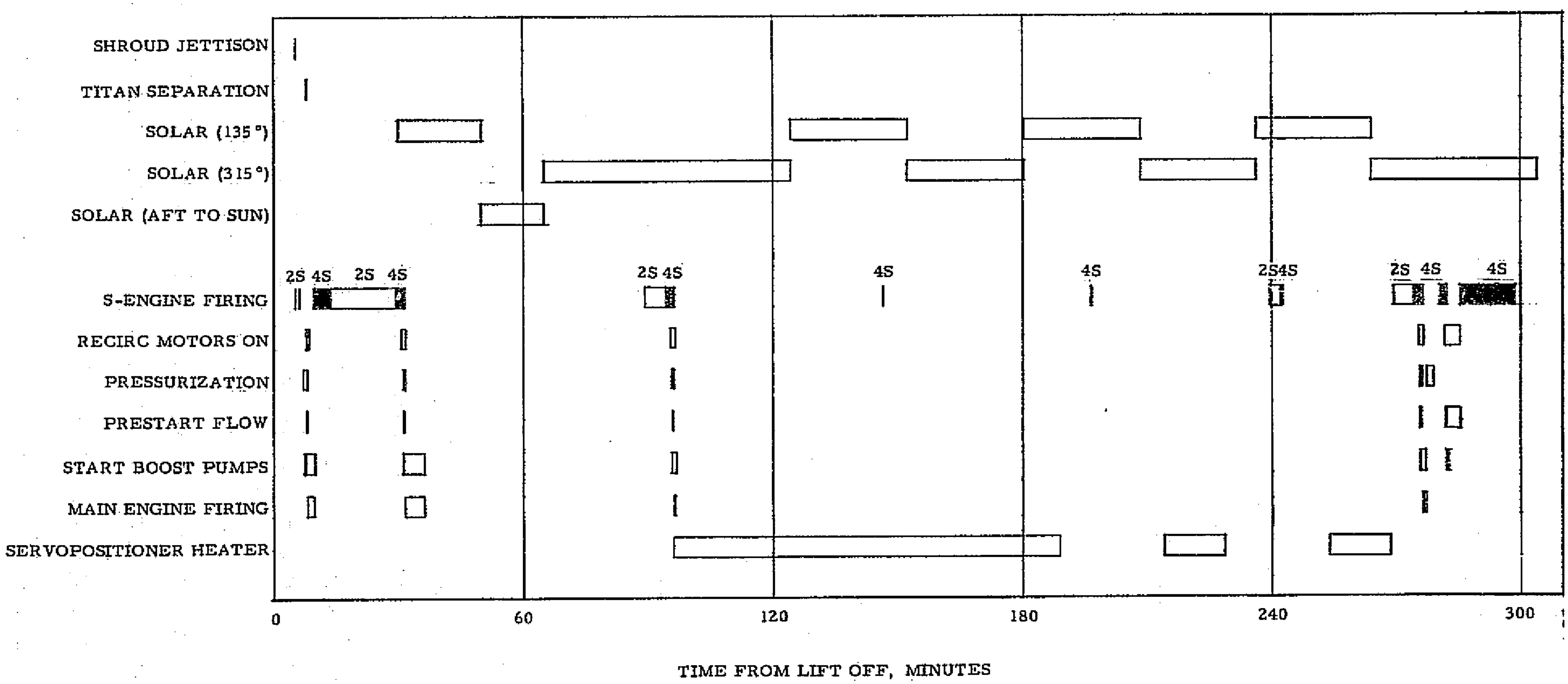
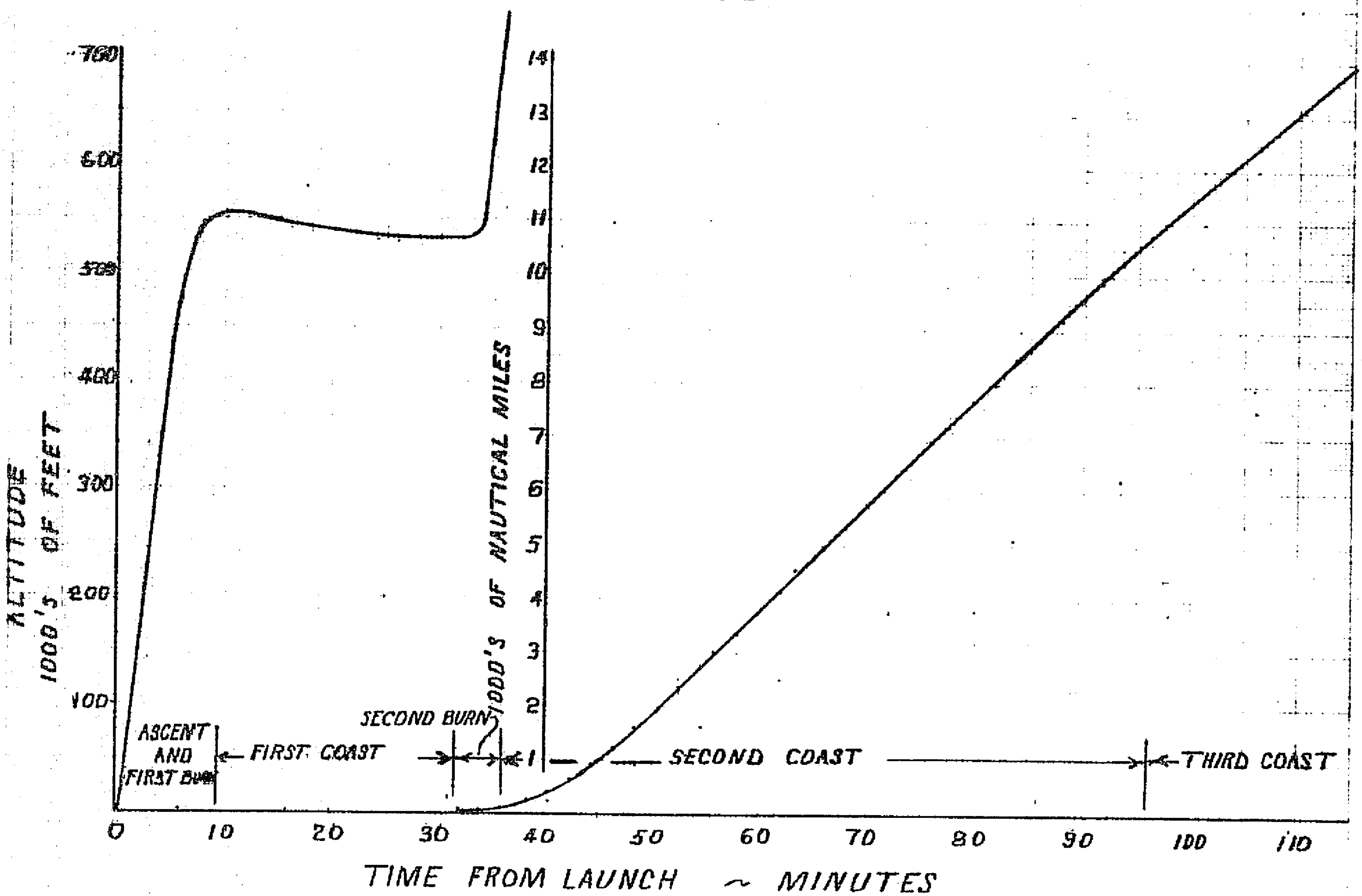
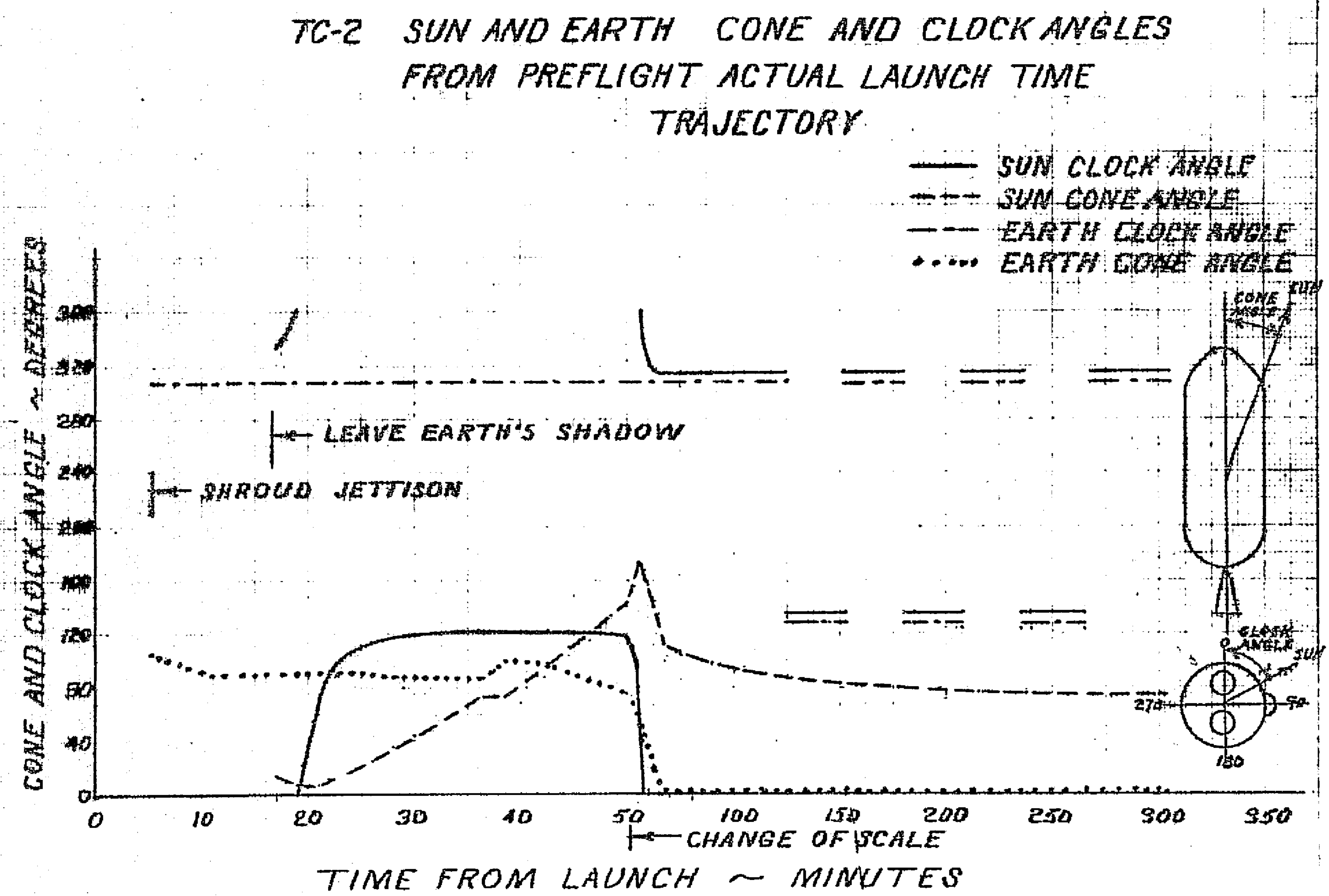
TC-2 VEHICLE INDUCED THERMAL ENVIRONMENT SEQUENCES



CENTAUR ALTITUDE

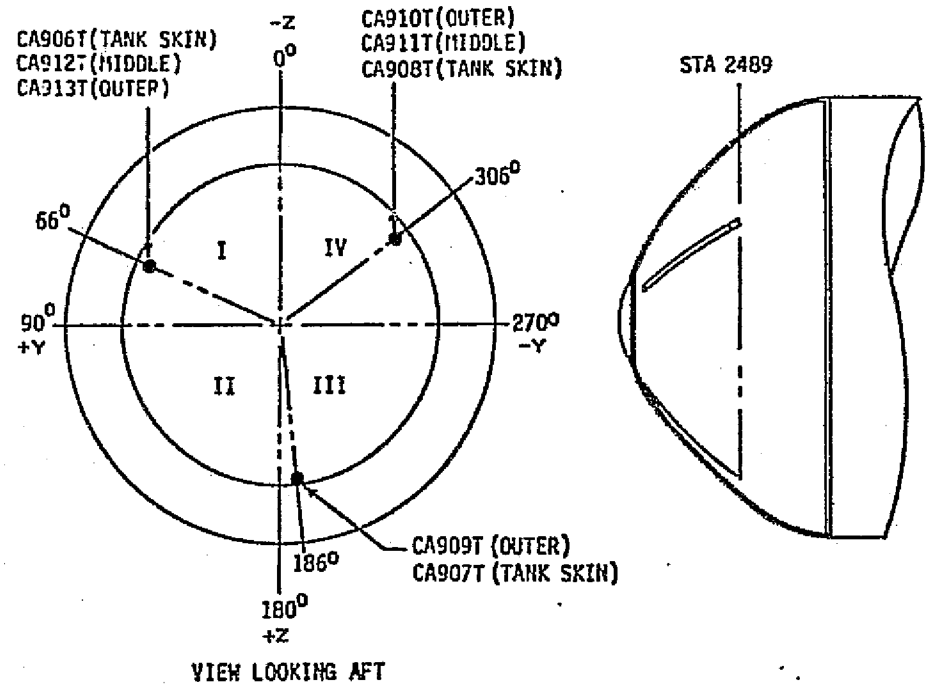




TC-2 SUN AND EARTH CONE AND CLOCK ANGLES
FROM PREFLIGHT ACTUAL LAUNCH TIME
TRAJECTORY
SUN CLOCK ANGLE
SUN CONE ANGLE
EARTH CLOCK ANGLE
EARTH CONE ANGLE
LEAVE EARTH'S SHADOW
SHROUD JETTISON
CONE AND CLOCK ANGLE ~ DEGREES
0
40
80
120
160
240
280
320
360
0
10
20
30
40
50
100
150
200
250
300
350
CHANGE OF SCALE
TIME FROM LAUNCH ~ MINUTES
CONE ANGLE
SUN
CLOCK ANGLE
0
270
90
180

THERMAL AND HEAT TRANSFER

- PRELAUNCH THERMAL CONTROL BY GAS CONDITIONING AND PURGING
- PRELAUNCH TANK HEATING
- ASCENT THERMAL ENVIRONMENT AND RESPONSE
- SPACE AND VEHICLE INDUCED ENVIRONMENT
- FORWARD BULKHEAD MULTILAYER INSULATION
  - — THERMAL RESPONSE AND PERFORMANCE
- THREE-LAYER SHIELDING
  - — THERMAL RESPONSE AND PERFORMANCE
- TITANIUM STUB ADAPTER AND GROUND PLANE/SHIELD
  - — THERMAL RESPONSE AND PERFORMANCE
- WIRING MODULE STRUCTURE/TYPICAL PENETRATION
  - — THERMAL RESPONSE AND PERFORMANCE
- LH_2 TANK FLIGHT HEAT RATES



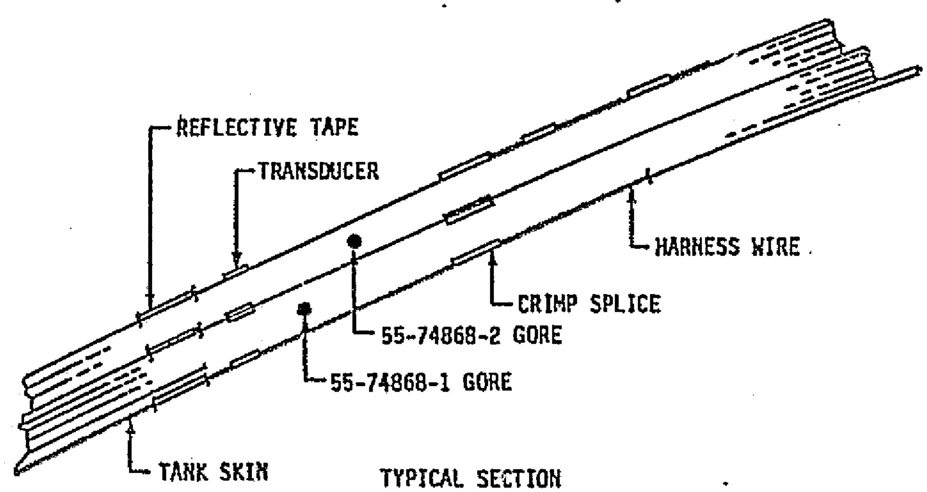
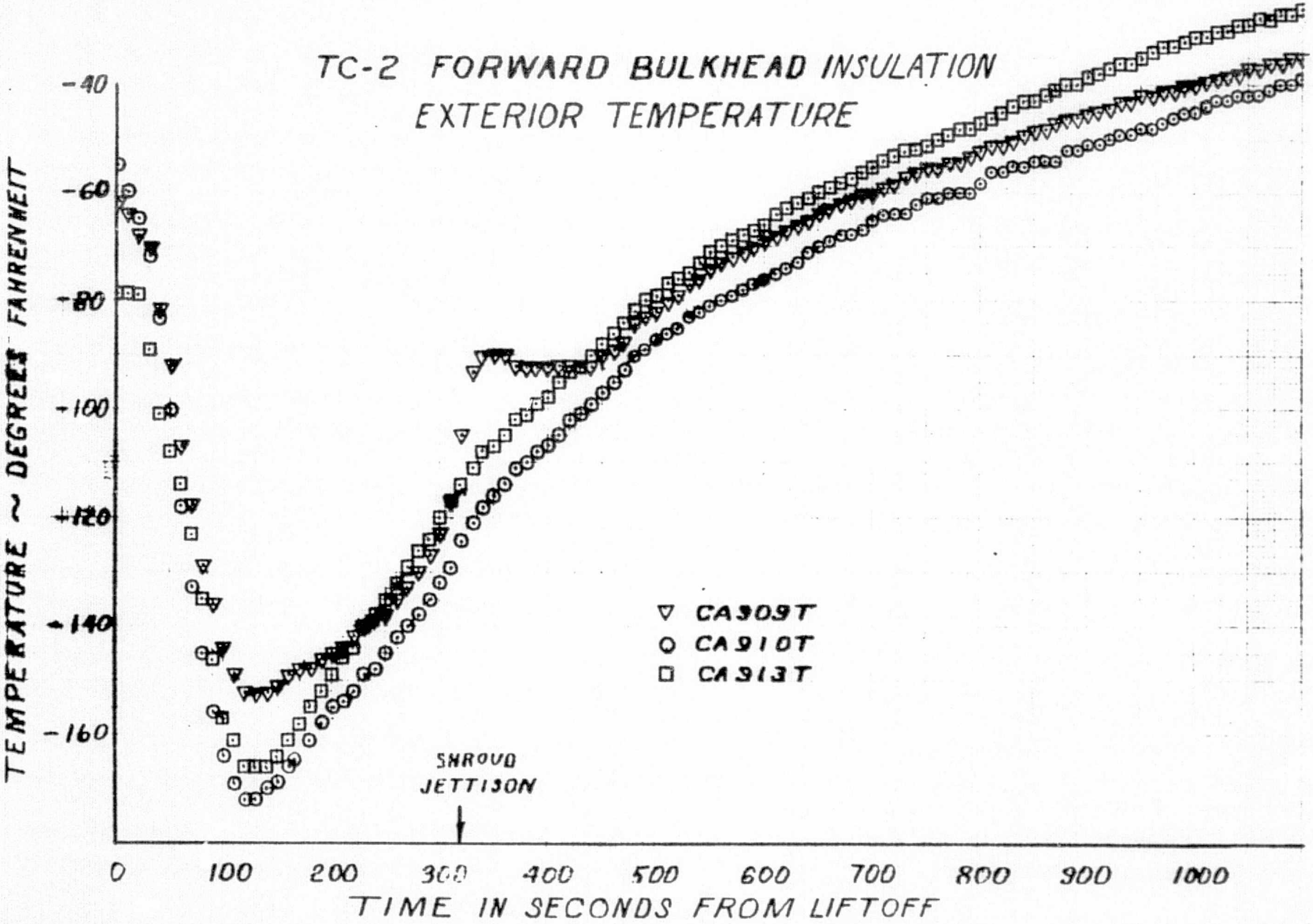
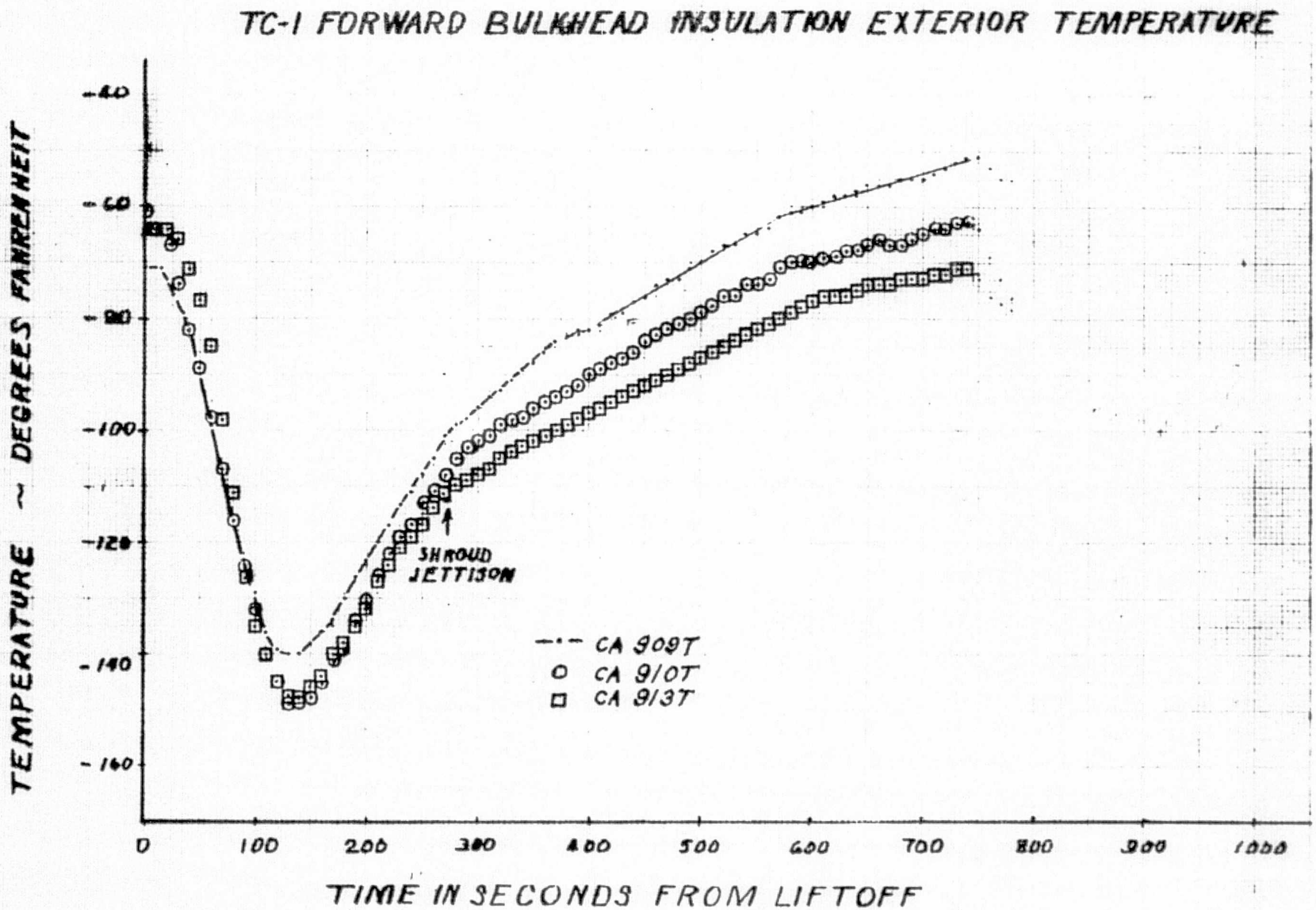


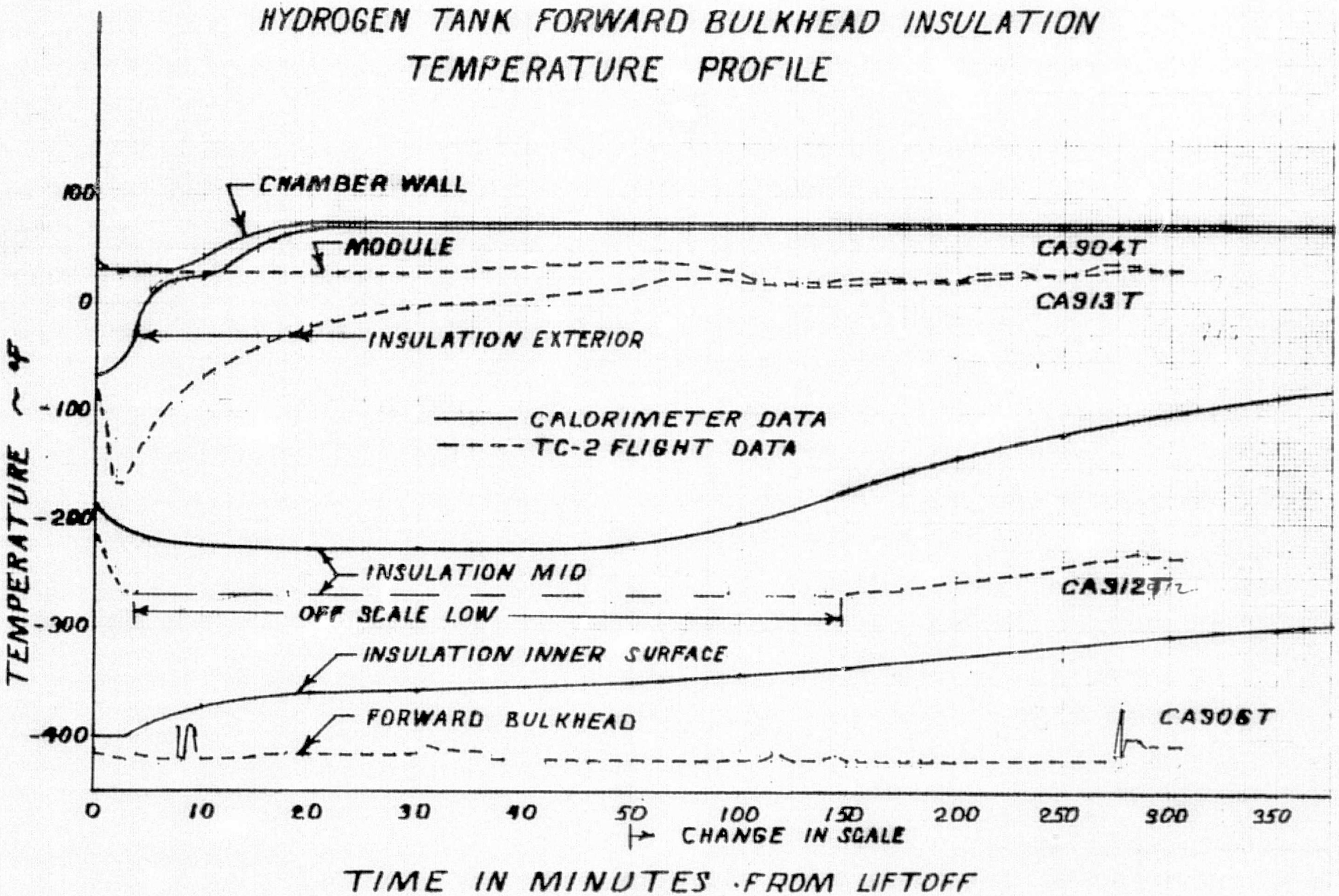
Figure   Forward bulkhead insulation temperature instrumentation.

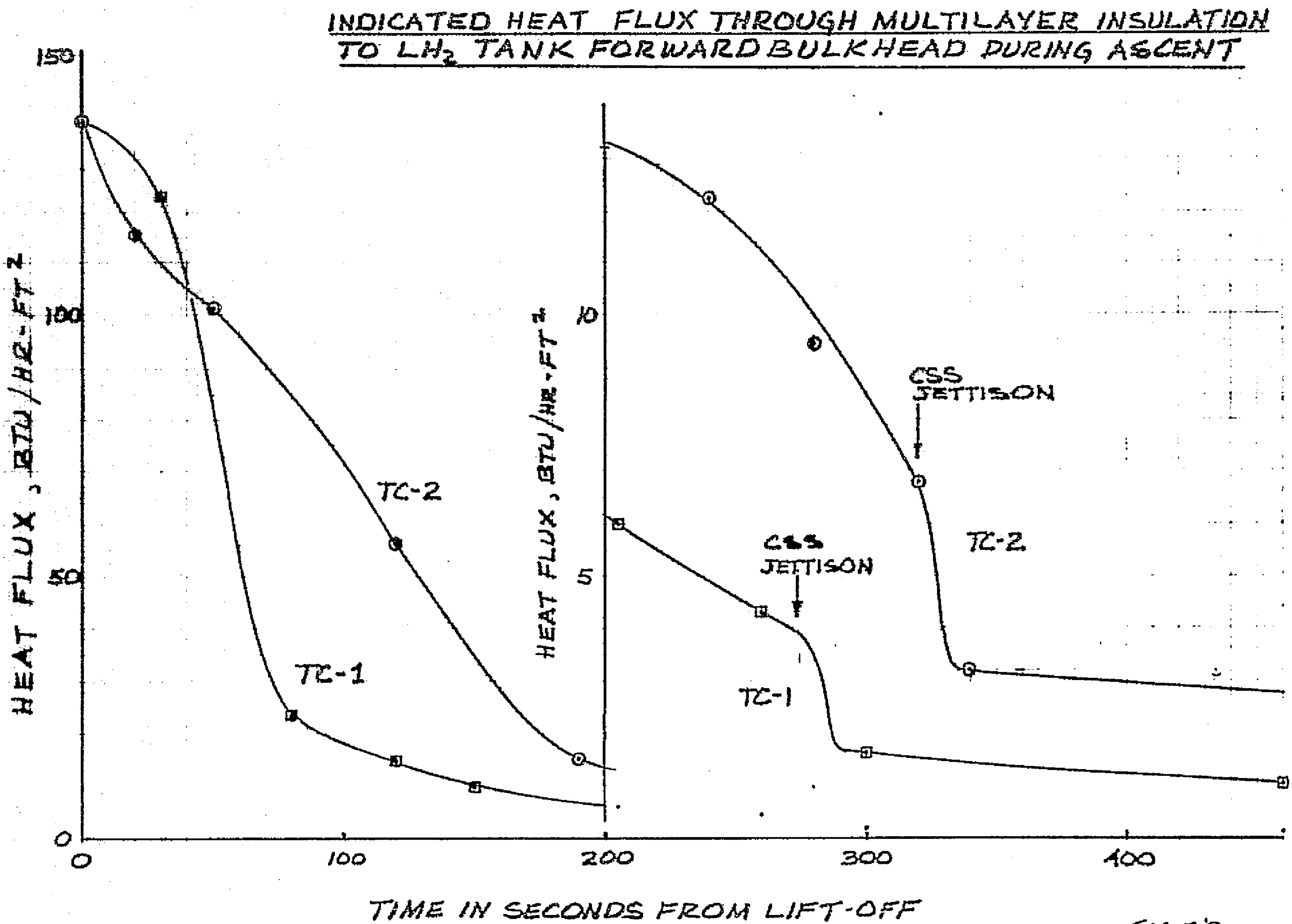

TC-2 FORWARD BULKHEAD INSULATION
EXTERIOR TEMPERATURE
TEMPERATURE ~ DEGREES FAHRENHEIT
-40
-60
-80
-100
-120
-140
-160
CA309T
CA910T
CA913T
SHROUD
JETTISON
0
100
200
300
400
500
600
700
800
900
1000
TIME IN SECONDS FROM LIFTOFF



TC-1 FORWARD BULKHEAD INSULATION EXTERIOR TEMPERATURE
TEMPERATURE ~ DEGREES FAHRENHEIT
-40
-60
-80
-100
-120
-140
-160
0
100
200
300
400
500
600
700
800
900
1000
TIME IN SECONDS FROM LIFTOFF
SHROUD JETTISON
CA 909T
CA 910T
CA 913T

6


HYDROGEN TANK FORWARD BULKHEAD INSULATION
TEMPERATURE PROFILE
CHAMBER WALL
MODULE
CA904T
CA913T
INSULATION EXTERIOR
CALORIMETER DATA
TC-2 FLIGHT DATA
INSULATION MID
CA912T
OFF SCALE LOW
INSULATION INNER SURFACE
FORWARD BULKHEAD
CA906T
TEMPERATURE ~ °F
100
0
-100
-200
-300
-400
0
10
20
30
40
50
100
150
200
250
300
350
CHANGE IN SCALE
TIME IN MINUTES FROM LIFTOFF



INDICATED HEAT FLUX THROUGH MULTILAYER INSULATION
TO LH_2 TANK FORWARD BULKHEAD DURING ASCENT
HEAT FLUX, BTU/HR-FT^2
150
100
50
0
TC-2
TC-1
HEAT FLUX, BTU/HR-FT^2
10
5
CSS
JETTISON
TC-2
CSS
JETTISON
TC-1
0
100
200
300
400
TIME IN SECONDS FROM LIFT-OFF

FIG 19

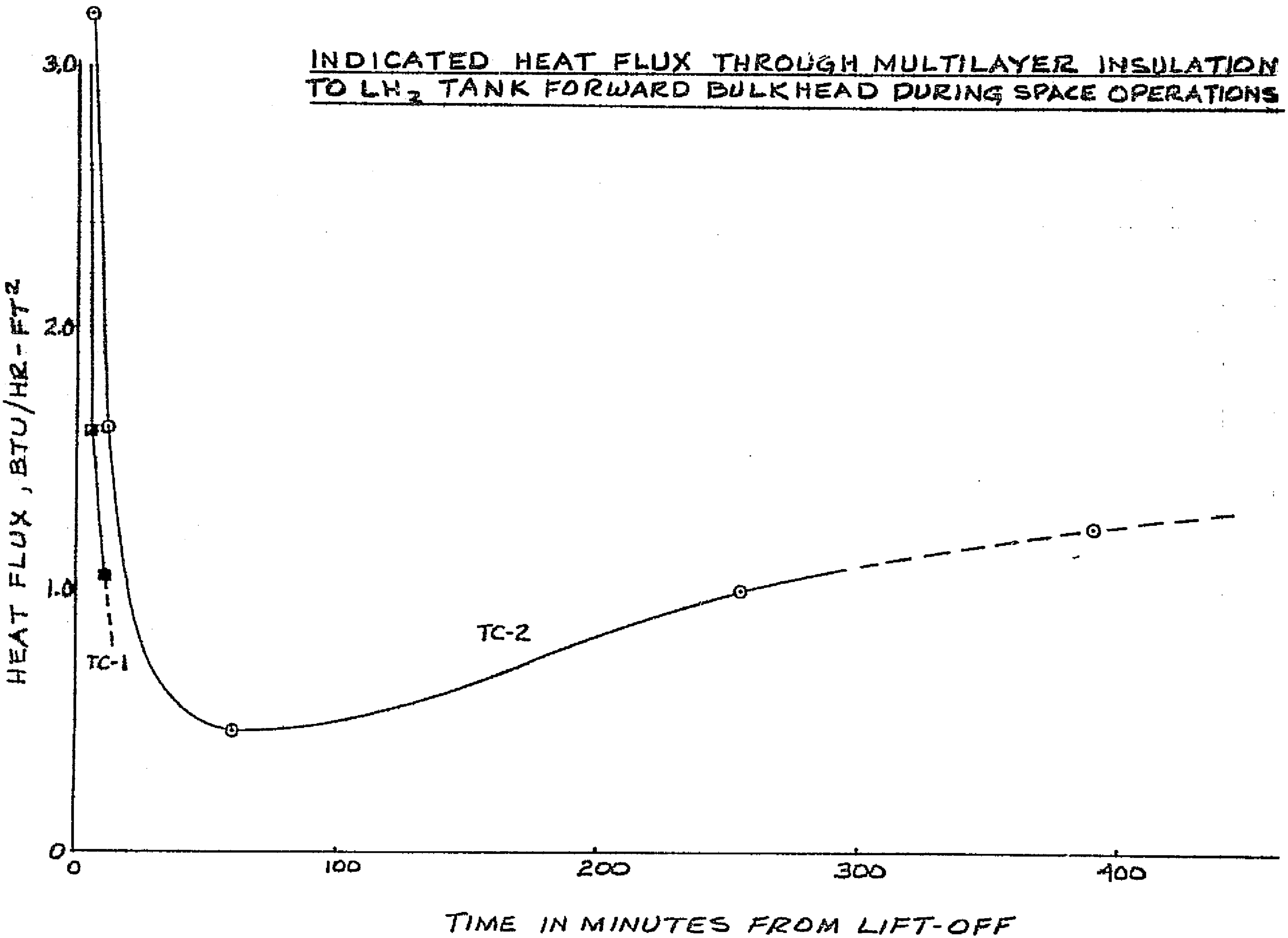

INDICATED HEAT FLUX THROUGH MULTILAYER INSULATION
TO LH2 TANK FORWARD BULKHEAD DURING SPACE OPERATIONS
HEAT FLUX, BTU/HR-FT2
3.0
2.0
1.0
0
TC-1
TC-2
0
100
200
300
400
TIME IN MINUTES FROM LIFT-OFF

Fig 7-9 cont'

THERMAL AND HEAT TRANSFER

- PRELAUNCH THERMAL CONTROL BY GAS CONDITIONING AND PURGING
- PRELAUNCH TANK HEATING
- ASCENT THERMAL ENVIRONMENT AND RESPONSE
- SPACE AND VEHICLE INDUCED ENVIRONMENT
- FORWARD BULKHEAD MULTILAYER INSULATION
  - THERMAL RESPONSE AND PERFORMANCE
- THREE-LAYER SHIELDING
  - THERMAL RESPONSE AND PERFORMANCE
- TITANIUM STUB ADAPTER AND GROUND PLANE/SHIELD
  - THERMAL RESPONSE AND PERFORMANCE
- WIRING MODULE STRUCTURE/TYPICAL PENETRATION
  - THERMAL RESPONSE AND PERFORMANCE
- LH_2 TANK FLIGHT HEAT RATES

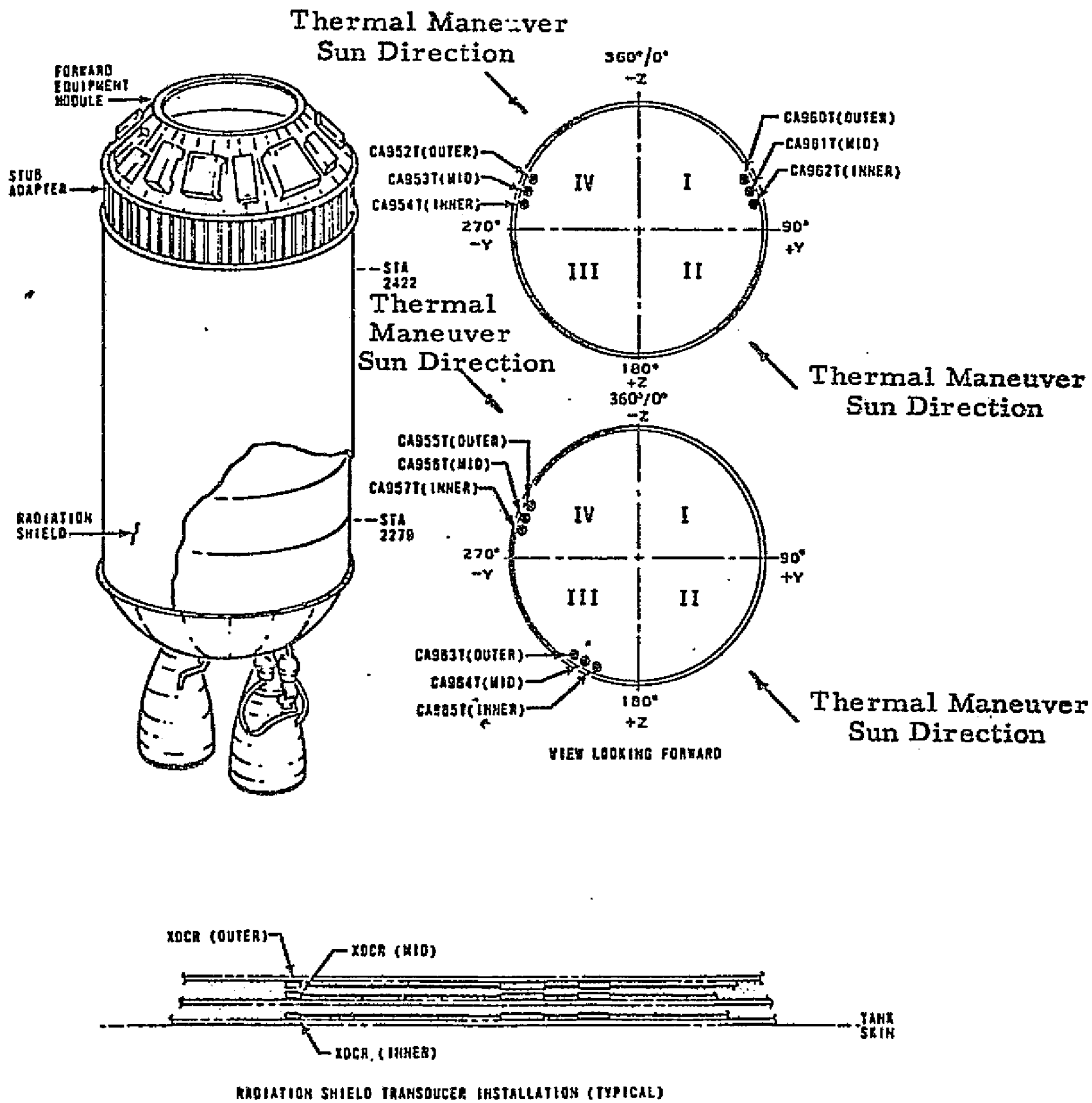
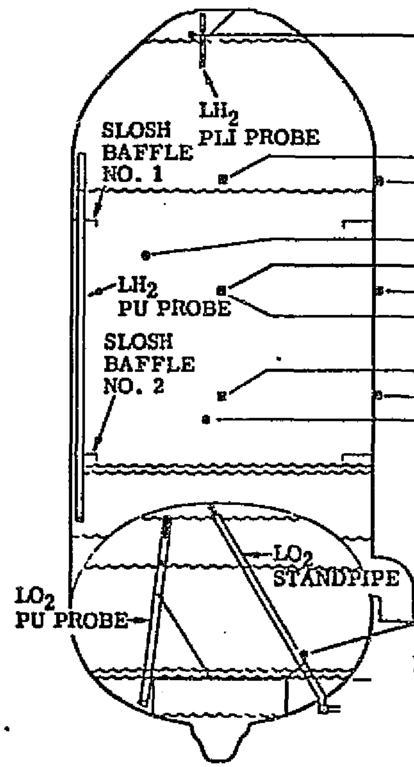


Figure LH$_2$ tank radiation shield temperature measurements.

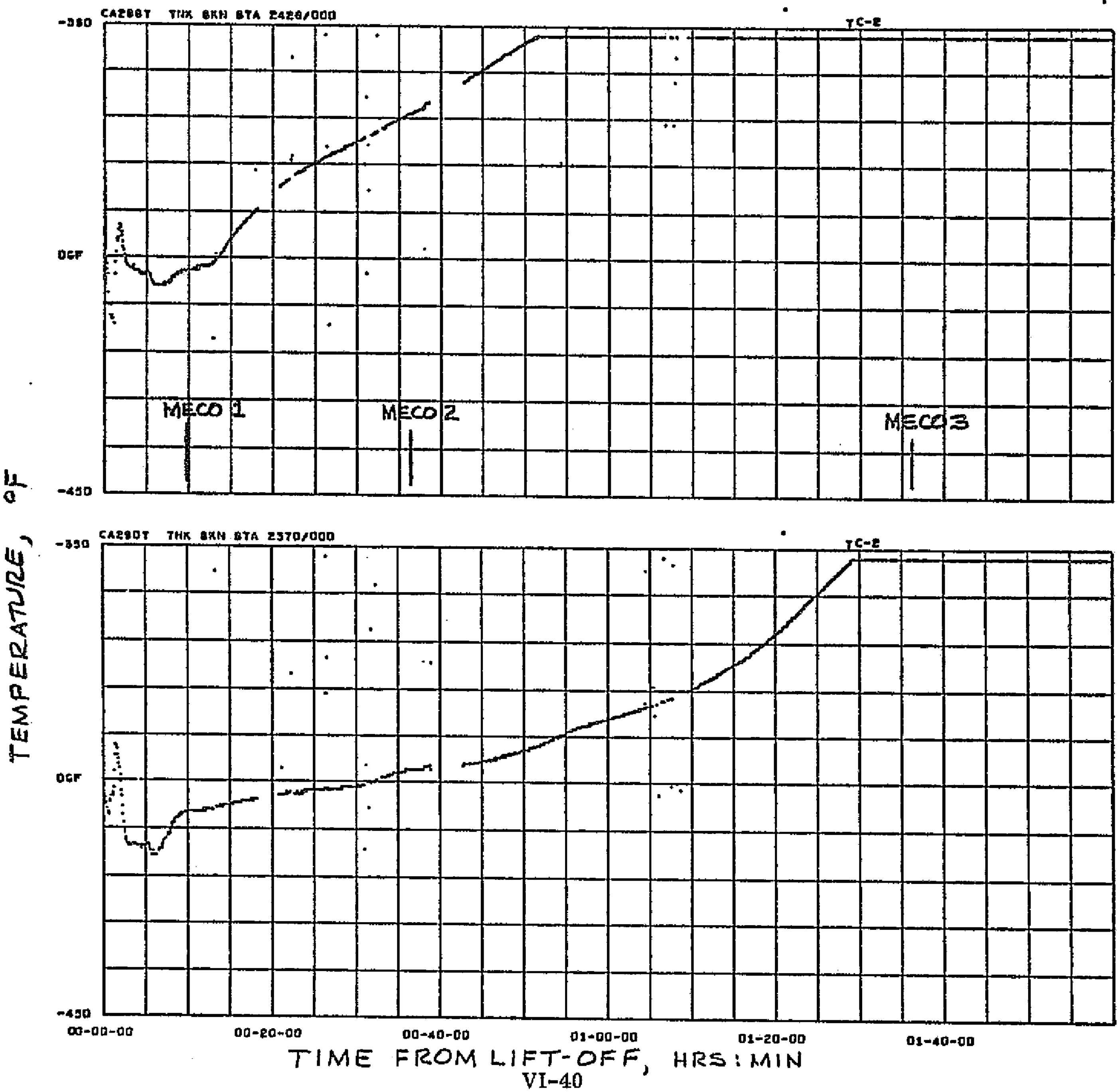


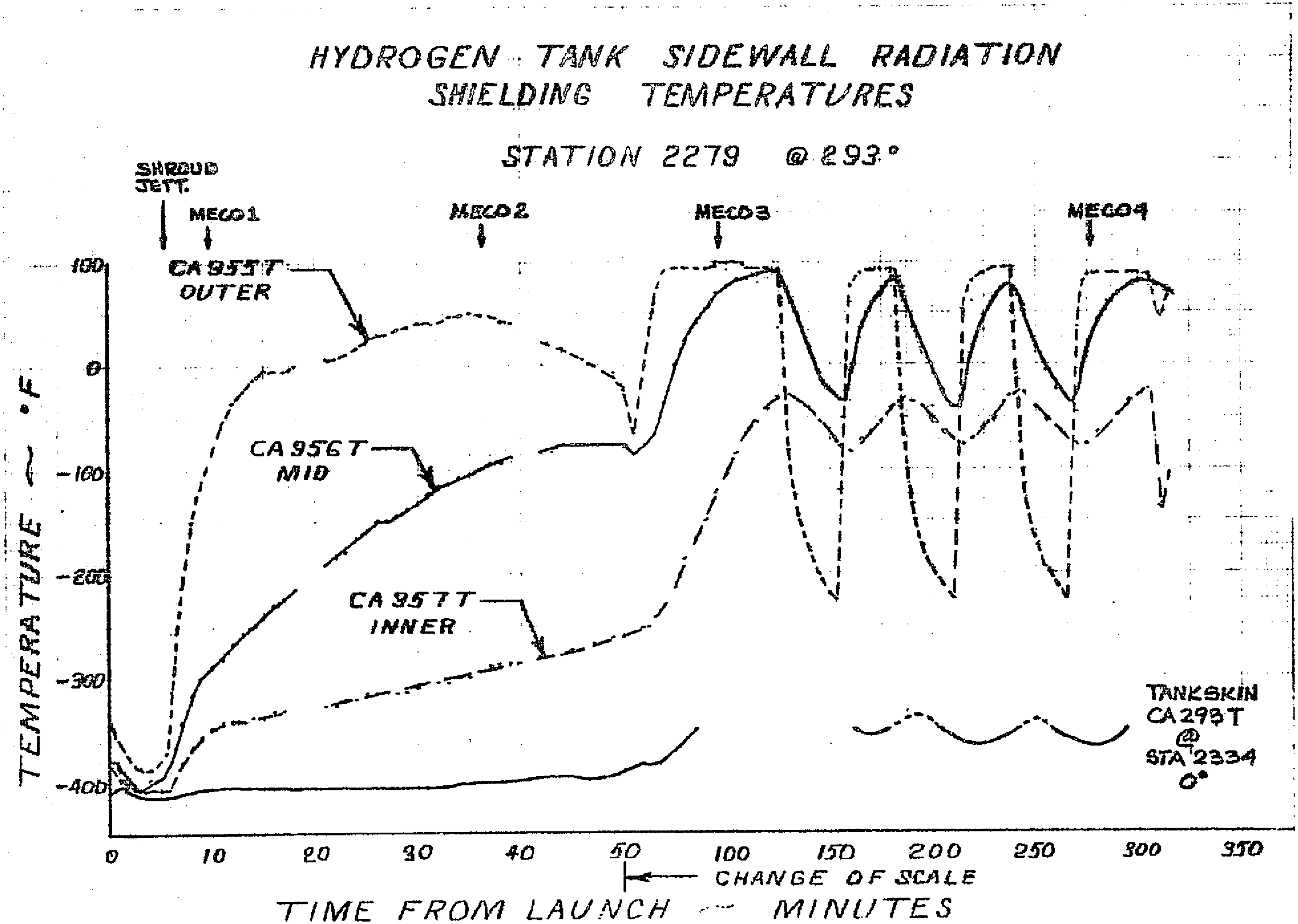
MEASUREMENT NUMBER (1)	LOCATION	
	STATION	RADIAL
CF24T	2473	330
CA288T	2426	0
CA289T	2426	90
CF25T	2387	310
CA290T	2370	0
CA291T	2370	90
CA292T	2370	180
CA293T	2334	0
CA294T	2334	90
CF27T	2320	195
CF23T	2230	60

NOTES: (1)
CF MEASUREMENTS (•) INTERNAL TO TANKS.
CA MEASUREMENTS (▪) MOUNTED ON EXTERNAL SURFACE OF LH_2 TANK.

Tank Temperature measurement locations.

TANK SKIN SENSOR RESPONSE TYPICAL OF DEBONDING




HYDROGEN TANK SIDEWALL RADIATION
SHIELDING TEMPERATURES
STATION 2279 @ 293°
SHROUD JETT.
MECO 1
MECO 2
MECO 3
MECO 4
CA 955 T
OUTER
CA 956 T
MID
CA 957 T
INNER
TANKSKIN
CA 293 T
@
STA 2334
0°
TEMPERATURE ~ °F
100
0
-100
-200
-300
-400
0
10
20
30
40
50
100
150
200
250
300
350
CHANGE OF SCALE
TIME FROM LAUNCH ~ MINUTES

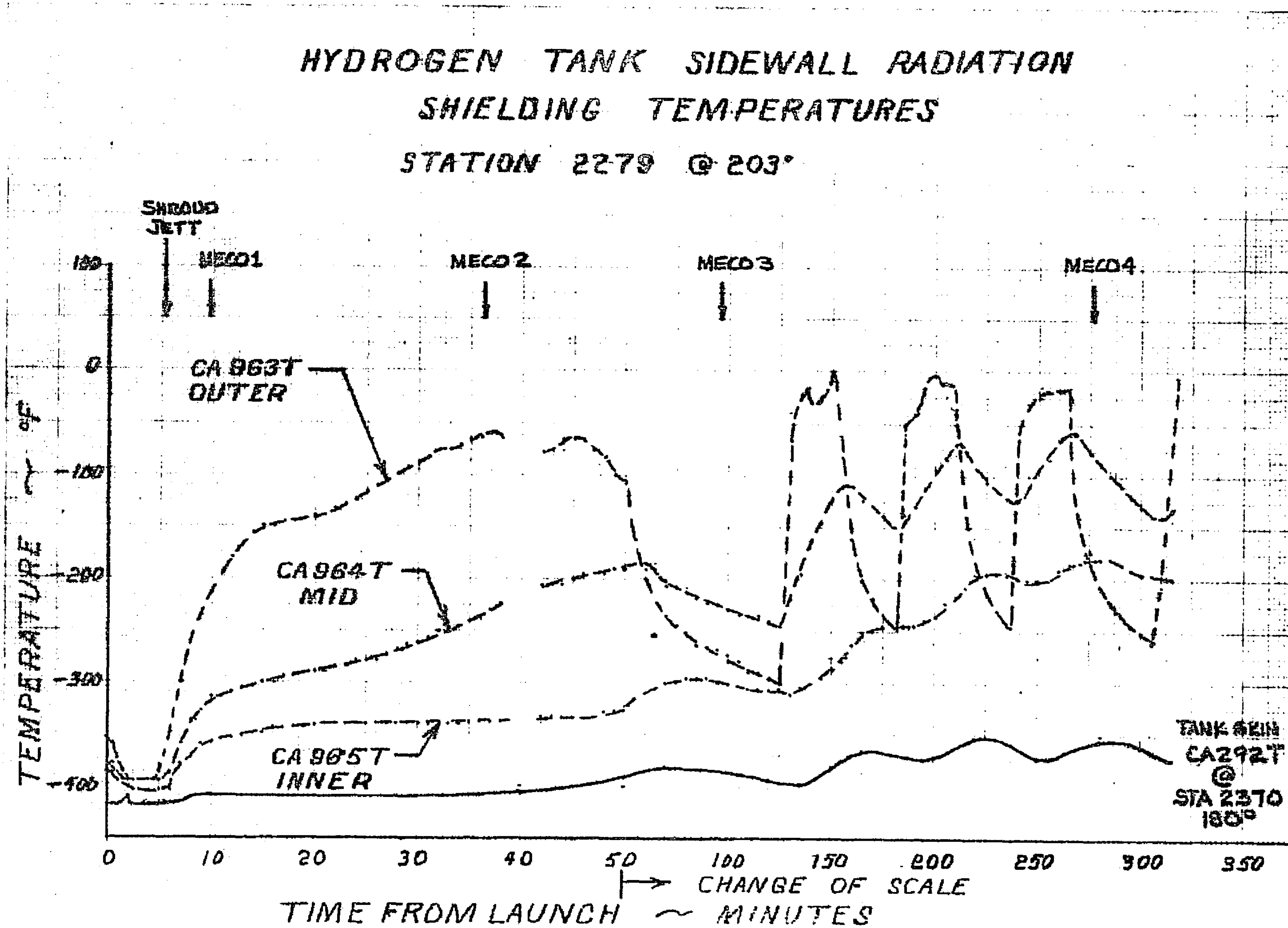
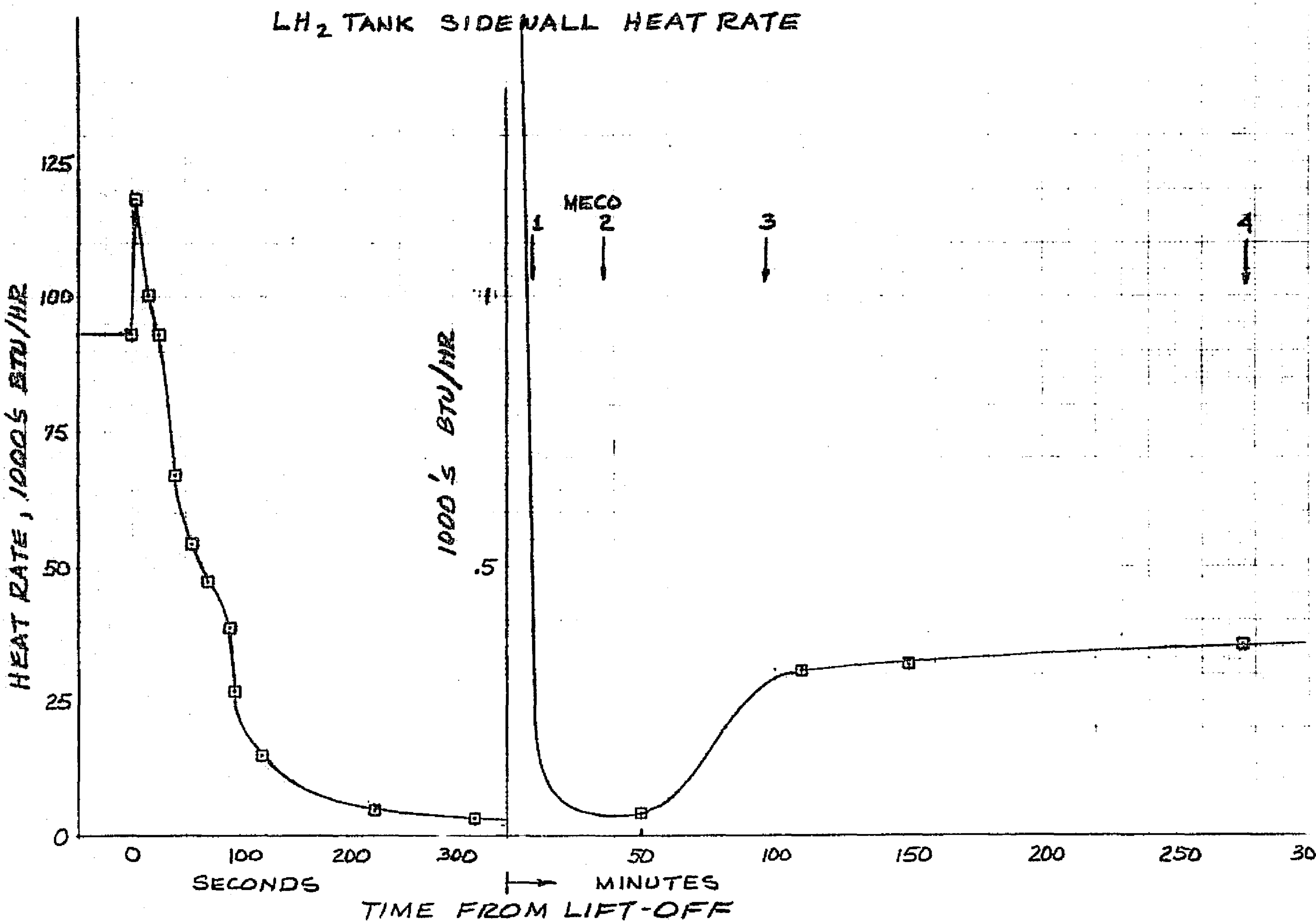

HYDROGEN TANK SIDEWALL RADIATION
SHIELDING TEMPERATURES
STATION 2279 @ 203°
SHROUD JETT
MECO1
MECO2
MECO3
MECO4
CA 963T OUTER
CA 964T MID
CA 965T INNER
TANK SKIN CA292T @ STA 2370 180°
TEMPERATURE ~ °F
100
0
-100
-200
-300
-400
0
10
20
30
40
50
100
150
200
250
300
350
CHANGE OF SCALE
TIME FROM LAUNCH ~ MINUTES

TABLE 7-VI

SPACE HEATING OF HYDROGEN TANK SIDE WALL SHIELDING - STA 2422 @ 293°

Time Minutes	Temp ~ °R			Outer Shield Flux, Btu/hr-ft^2					Mid Shield Flux, Btu/hr-ft^2				Inner Shield Flux, Btu/hr-ft^2		
	CA952T	CA953T	CA954T	Q_{solar}	Q_{re-rad}	$Q_{out-mid}$	Q_{net}	Q_{cal}	Q_{solar}	Q_{mid-in}	Q_{net}	Q_{cal}	Q_{in-tnk}	Q_{net}	Q_{cal}
125	554	554	419	108.9	-105.50	0	3.4	0	0.52	-1.74	-1.22	0	-1.28	0.46	1.48
130	378	536	425	0	- 22.87	1.89	-20.98	-22.87	0	-1.37	-3.26	-7.31	-1.35	0.02	0.81
135	310	513	425	0	- 10.34	1.80	- 8.54	- 7.84	0	-1.01	-2.81	-6.41	-1.35	-0.34	-1.08
140	276	483	419	0	- 6.50	1.42	- 5.08	- 3.70	0	-0.64	-2.06	-5.46	-1.28	-0.64	-1.68
145	259	460	407	0	- 5.04	1.16	- 3.88	- 2.34	0	-0.47	-1.63	-4.66	-1.14	-0.67	-1.74
150	248	442	401	0	- 4.24	0.99	- 3.25	- 1.80	0	-0.33	-1.32	-3.88	-1.07	-0.74	-1.73
155	360	435	395	108	- 18.8	0.60	89.8	88.8	0.52	-0.31	-0.39	0	-1.00	-0.69	-1.71
160	540	460	385	108	- 95.2	-1.28	11.5	10.8	0.52	-0.62	1.18	6.40	-0.90	-0.28	0
165	555	490	390	108	-106.3	-1.18	0.5	2.2	0.52	-0.94	0.76	6.24	-0.95	-0.01	1.42
170	560	510	395	108	-110.2	-0.98	- 3.2	0	0.52	-1.18	0.32	5.02	-1.00	0.18	2.05
175	560	530	410	108	-110.2	-0.62	- 2.8	0	0.52	-1.39	-0.25	3.17	-1.16	0.23	2.10
180	560	540	420	108	-110.2	-0.42	- 2.6	0	0.52	-1.48	-0.54	2.58	-1.28	0.20	2.14

Thermal Maneuver Average Inner Shield-to-Tank Heat Rate = $\frac{-13.76}{12}$ = -1.15 Btu/hr-ft^2


LH2 TANK SIDEWALL HEAT RATE
HEAT RATE, 1000'S BTU/HR
1000'S BTU/HR
MECO
1
2
3
4
125
100
75
50
25
0
1
.5
0
100
200
300
50
100
150
200
250
300
SECONDS
MINUTES
TIME FROM LIFT-OFF

SUMMARY OF 3-LAYER RADIATION SHIELDING APPLICATION AND PRE-LAUNCH CONDITIONING

Shielding Application	Interlayer Net Separator	Shield System Stand-Off	Subsurface	Protected Fluid or Item	Lift-Off Thermal Conditions: Gas/Min Temp (1)	Lift-Off Thermal Conditions: Shield Temp °F Min Inner	Lift-Off Thermal Conditions: Shield Temp °F Max Outer	Indicated Space Thermal Performance - Flux or Qualitative (4)
Tank Sidewall	None	Yes	Bare CRES	LH_2	He/Cold	-385	-115	0.7 Btu/hr-ft^2
LH_2 Sump Fwd of Bulkhead	Yes	No	Bare CRES	LH_2	He/Cold	-380	-350	Double Above (3)
LH_2 Sump Aft of Bulkhead	Yes	No	White Painted F.G. Wrapped Foam	LH_2	GN_2/70°F	--	+20	Meas. Failed
LH_2 Feed Line	Yes	No	Tedlar/Mylar Shield Over Foam-He Purged Pre-Launch	LH_2	GN_2/55°F	+45	+55	1.6 to 2.7 Btu/hr-ft^2 (3)
LO_2 Tank Periphery	Yes	No	Bare CRES	LO_2	GN_2/0°F	-205	-55	1.25 Btu/hr-ft^2
LO_2 Sump	Yes	No	Aluminized Mylar Over Foam	LO_2	GN_2/65°F	-10	+50	(3)
LO_2 Feed Line	Yes	No	Tedlar/Mylar Shield Over Foam	LO_2	GN_2/60°F	--	+40	1.4 to 4.0 Btu/hr-ft^2 (3)
Membrane Under Hard Shield	None	Random	Bare CRES	LO_2	GN_2/Cool	-55 (2)	+30	2.7 Btu/hr-ft^2
Mechanical/Electronic Equip	Yes	No	Bare & Painted Metal/Plastics	Component	GN_2/50°F	Ambient		<1.0 Btu/hr-ft^2 (3)
Mechanical Equipment	Yes	No	Aluminized Mylar Over Foam on Lines	H_2O_2	GN_2/65°F	Ambient		<1.0 Btu/hr-ft^2 (3)

(1) Helium gas dew point is < -63.5°F.
Nitrogen gas dew point entering ISA is < -20°F.

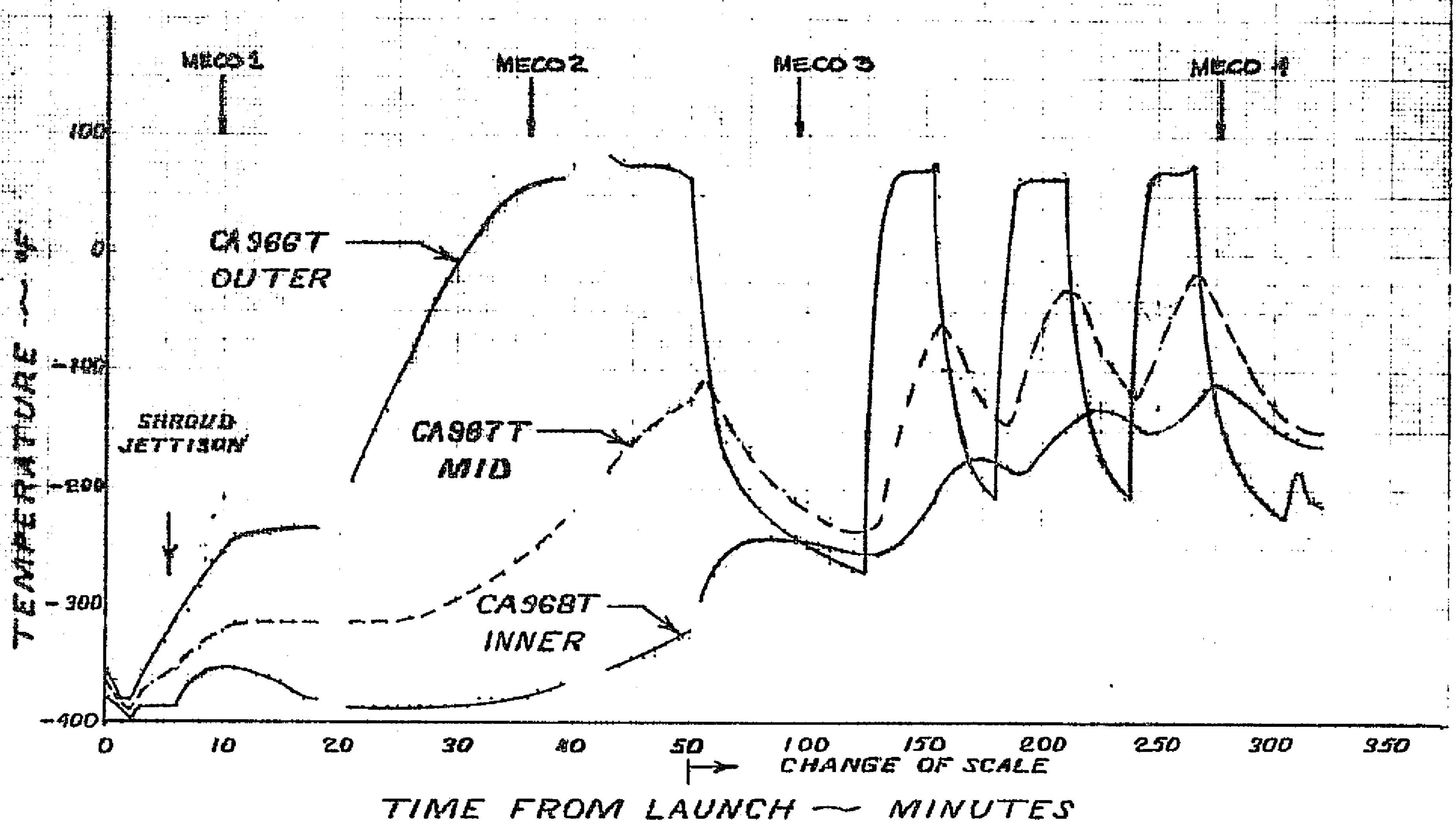
(2) Taken from TC-1 since no measurement on TC-2.

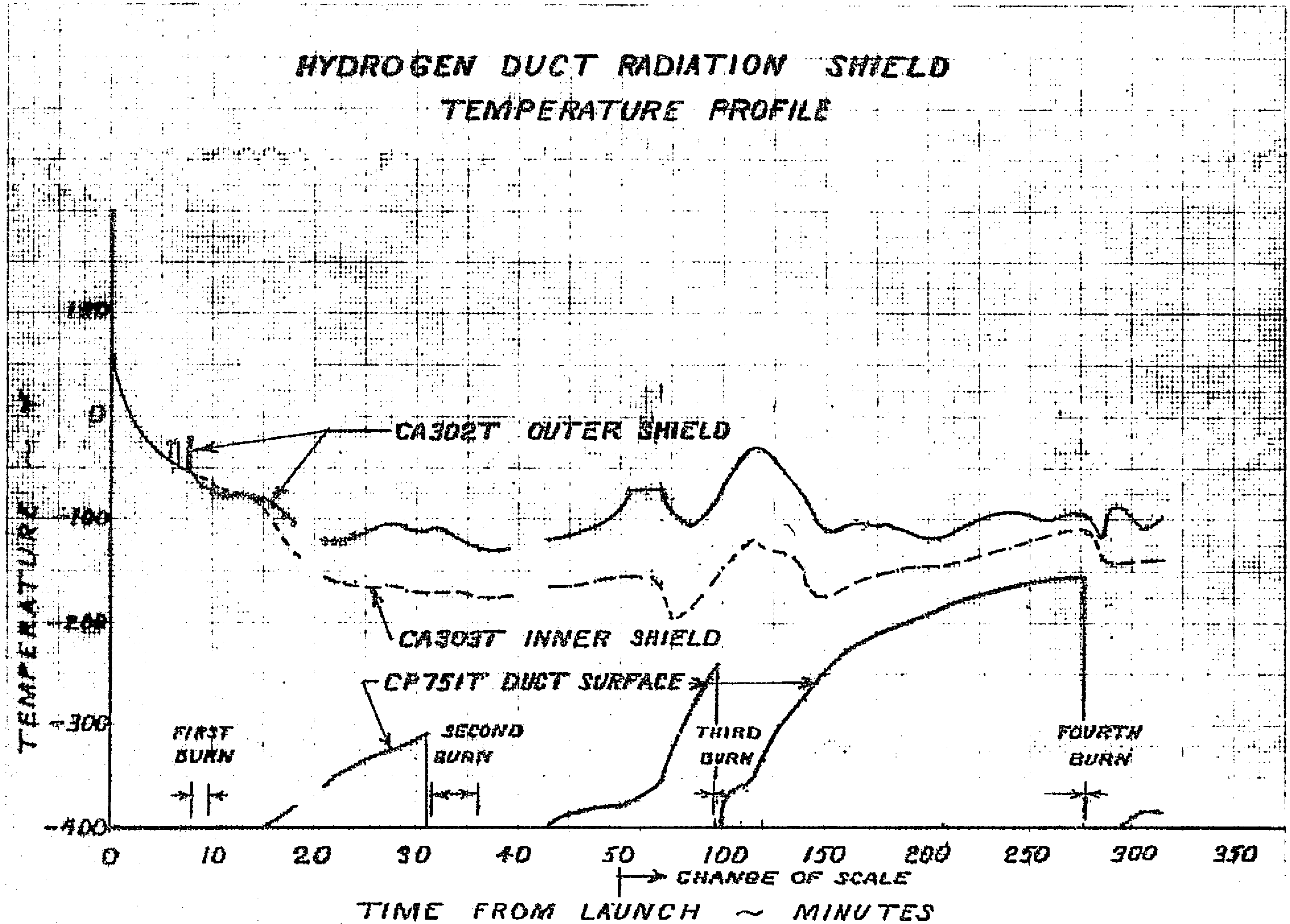
(3) Resolution of low heat flux is poor.

(4) Indicated heat flux through shielding compares to maximum 125 Btu/hr-ft^2 solar flux absorbed on outer shield.

HYDROGEN TANK SUMP RADIATION SHIELD TEMPERATURE PROFILE

STA 2247 @ 90°




HYDROGEN DUCT RADIATION SHIELD
TEMPERATURE PROFILE
CA302T OUTER SHIELD
CA303T INNER SHIELD
CP751T DUCT SURFACE
FIRST BURN
SECOND BURN
THIRD BURN
FOURTH BURN
TEMPERATURE
-100
-200
-300
-400
0
10
20
30
40
50
100
150
200
250
300
350
CHANGE OF SCALE
TIME FROM LAUNCH ~ MINUTES

THERMAL AND HEAT TRANSFER

- PRELAUNCH THERMAL CONTROL BY GAS CONDITIONING AND PURGING
- PRELAUNCH TANK HEATING
- ASCENT THERMAL ENVIRONMENT AND RESPONSE
- SPACE AND VEHICLE INDUCED ENVIRONMENT
- FORWARD BULKHEAD MULTILAYER INSULATION
  — THERMAL RESPONSE AND PERFORMANCE
- THREE-LAYER SHIELDING
  — THERMAL RESPONSE AND PERFORMANCE
- TITANIUM STUB ADAPTER AND GROUND PLANE/SHIELD
  — THERMAL RESPONSE AND PERFORMANCE
- WIRING MODULE STRUCTURE/TYPICAL PENETRATION
  — THERMAL RESPONSE AND PERFORMANCE
- LH_2 TANK FLIGHT HEAT RATES

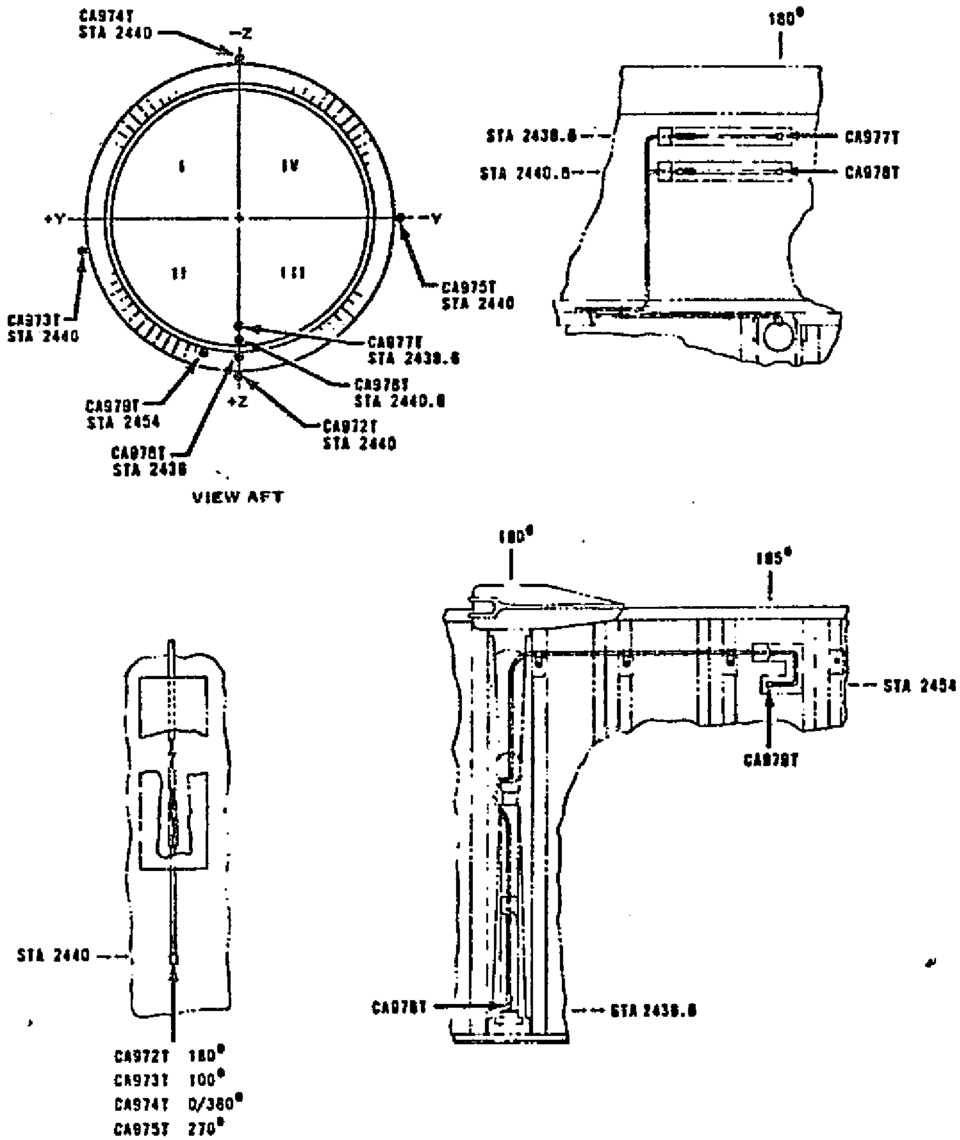
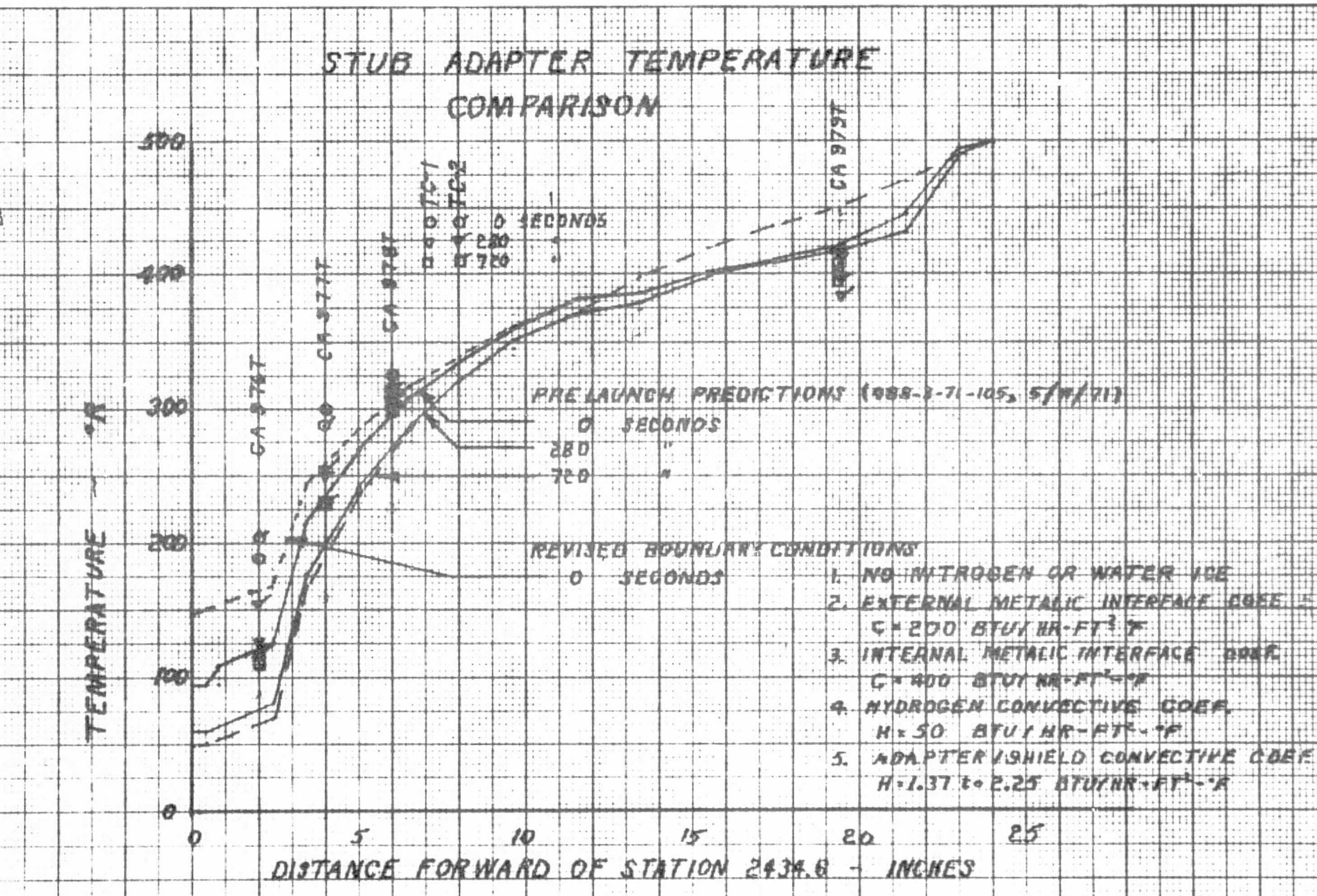
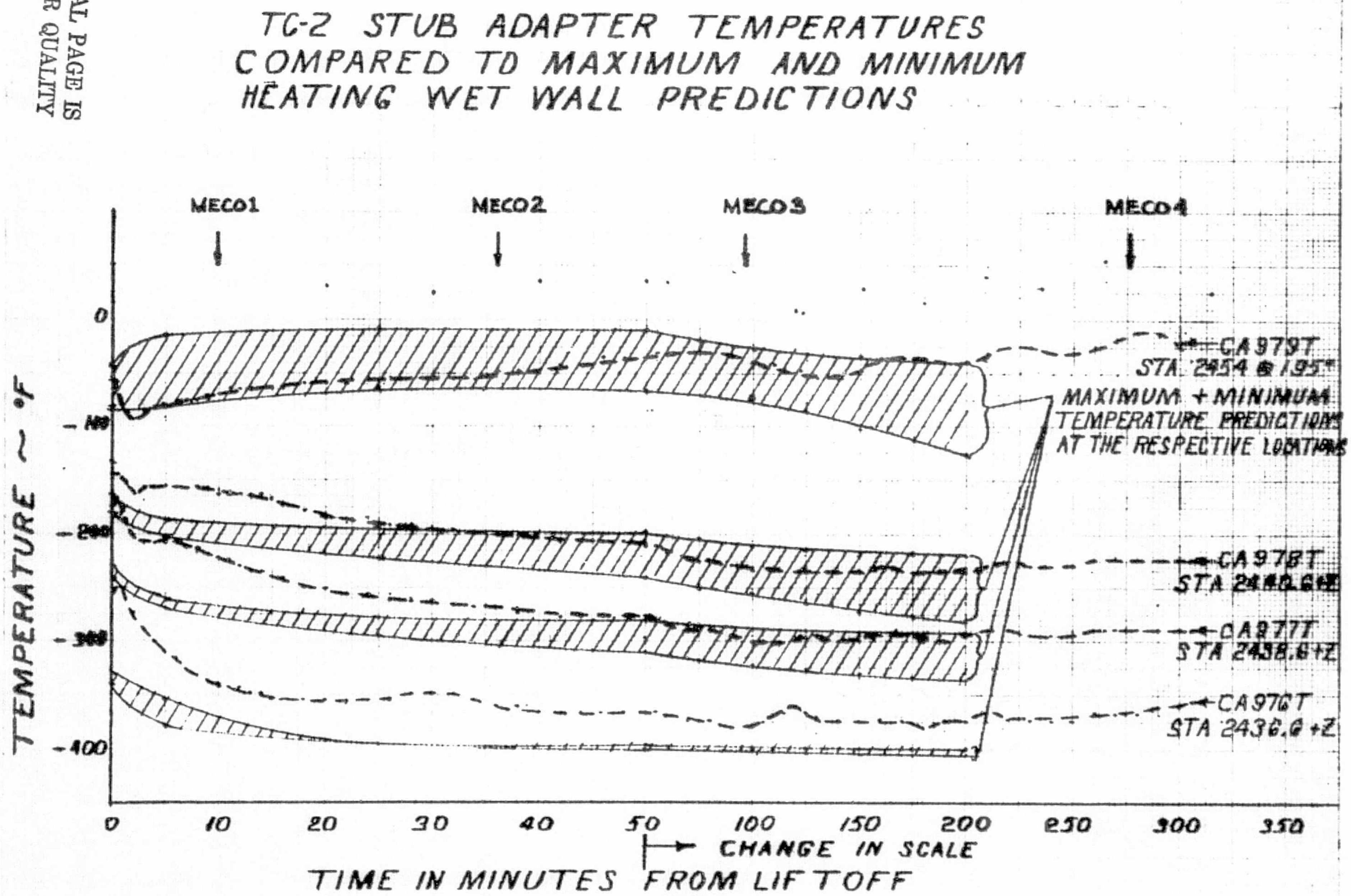


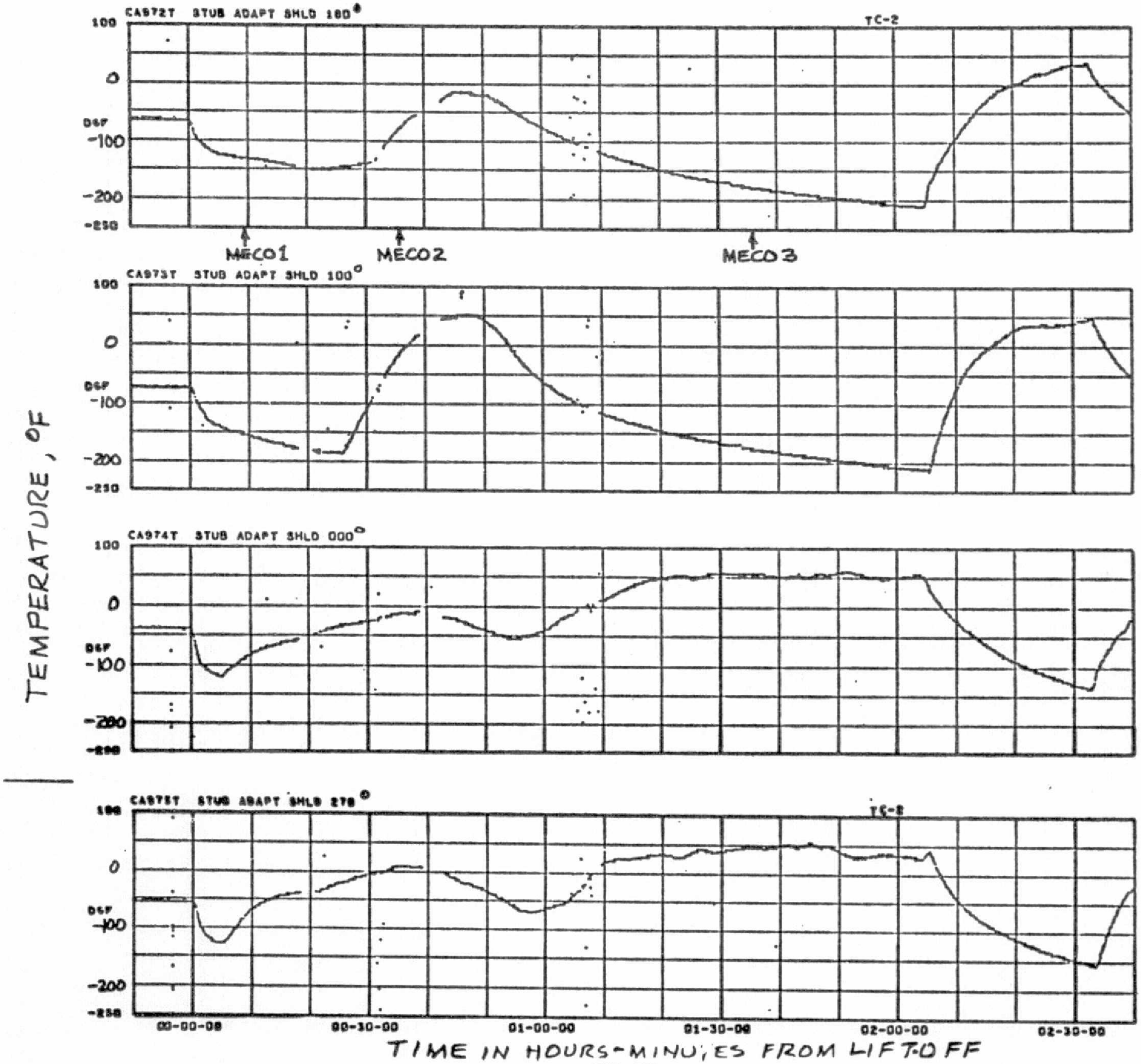
Figure Stub adapter and shield temperature measurements.



STUB ADAPTER TEMPERATURE
COMPARISON
0 SECONDS
280 "
720 "
CA 9797T
CA 9787T
CA 9777T
CA 9747T
PRELAUNCH PREDICTIONS
0 SECONDS
280 "
720 "
REVISED BOUNDARY CONDITIONS
0 SECONDS
1. NO NITROGEN OR WATER ICE
2. EXTERNAL METALIC INTERFACE COEF.
C = 200 BTU/HR-FT² °F
3. INTERNAL METALIC INTERFACE COEF.
C = 400 BTU/HR-FT² °F
4. HYDROGEN CONVECTIVE COEF.
H = 50 BTU/HR-FT² - °F
5. ADAPTER/SHIELD CONVECTIVE COEF.
H = 1.37 to 2.25 BTU/HR-FT² - °R
TEMPERATURE - °R
DISTANCE FORWARD OF STATION 2434.6 - INCHES
0
100
200
300
400
500
0
5
10
15
20
25


TC-2 STUB ADAPTER TEMPERATURES
COMPARED TO MAXIMUM AND MINIMUM
HEATING WET WALL PREDICTIONS
MECO1
MECO2
MECO3
MECO4
CA979T
MAXIMUM + MINIMUM
TEMPERATURE PREDICTIONS
AT THE RESPECTIVE LOCATIONS
CA978T
CA977T
STA 2438.6+Z
CA976T
STA 2436.6 +Z
0
-400
0
10
20
30
40
50
100
150
200
250
300
350
CHANGE IN SCALE
TEMPERATURE ~ °F
TIME IN MINUTES FROM LIFTOFF

STUB ADAPTER RADIATION SHIELD TEMPERATURE HISTORIES



STUB ADAPTER RADIATION SHIELD TEMPERATURE HISTORIES

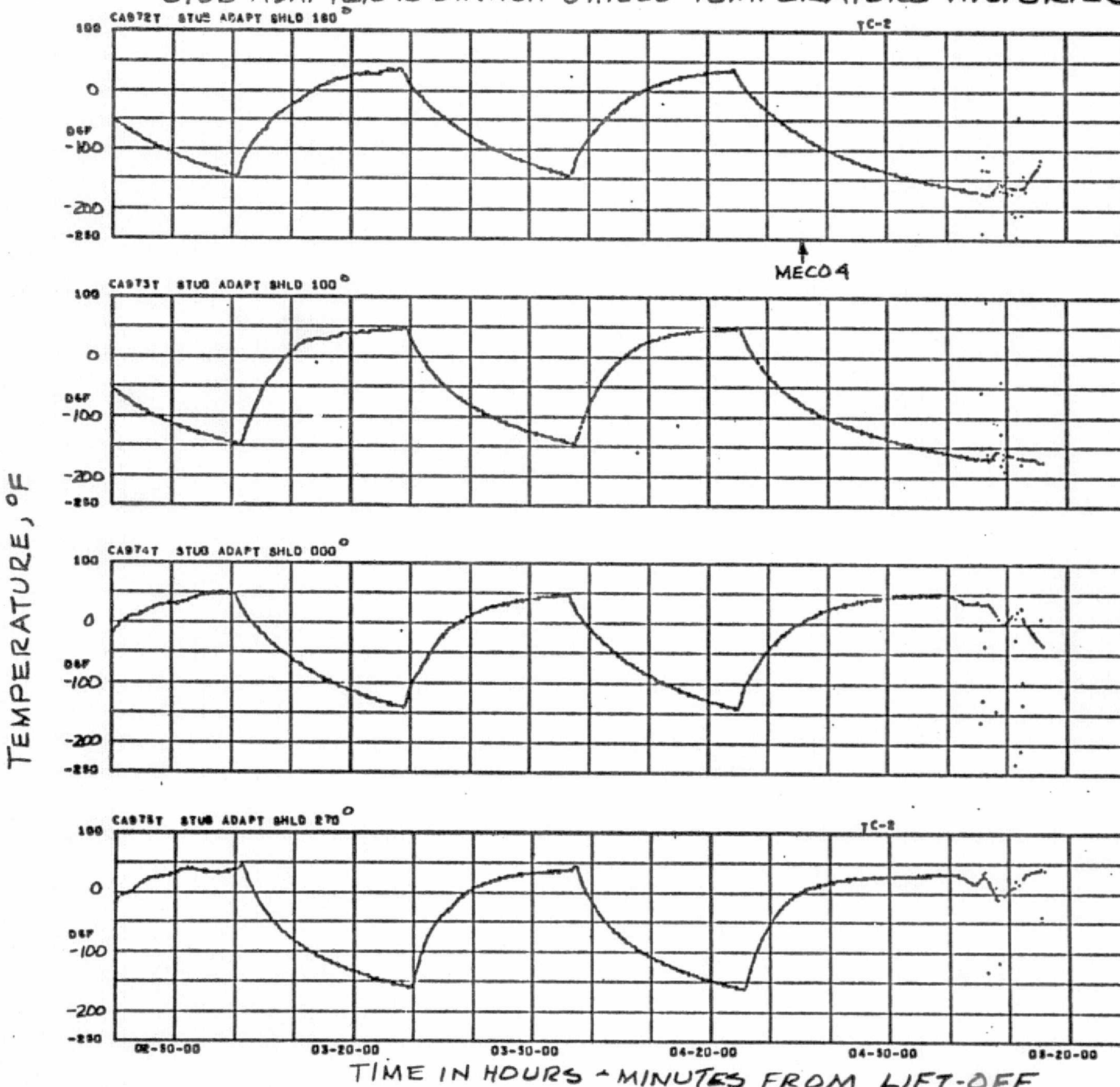
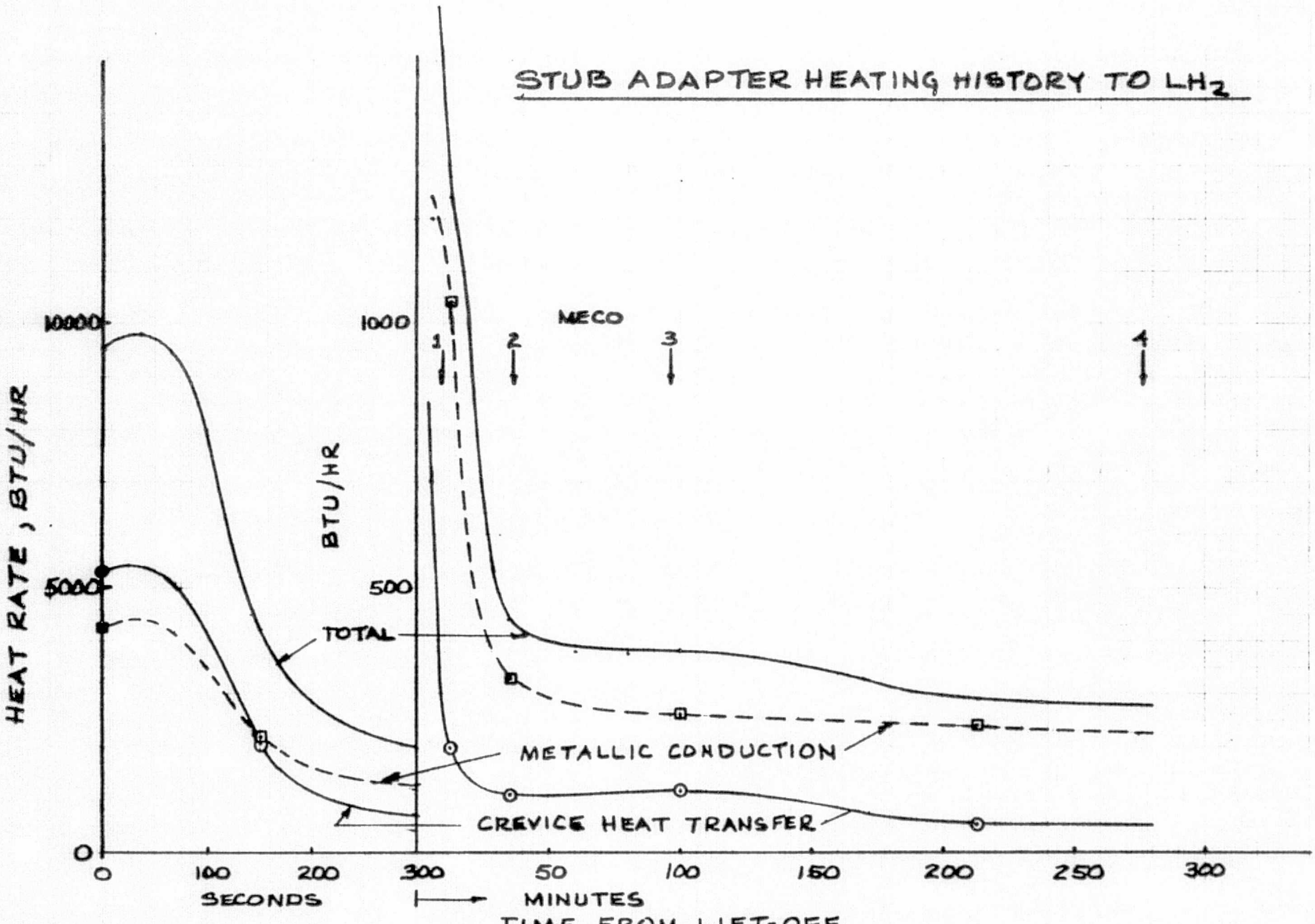


TABLE 7-IV. SPACE HEATING OF STUB ADAPTER SHIELD AT 180° (CA972T).

TIME HR:MIN	TEMP °R	BTU/HR-FT²				
		Q_{SOLAR}	Q_{RE-RAD}	$Q_{ADAPTER}$	Q_{NET}	$Q_{CALORIMETRIC}$
2:05	257	0	-6.3	-0.1	-6.4	-1.5
2:06	275	91.1	-8.3	-0.2	82.6	93.2
2:07	315	91.1	-14.3	-0.5	76.3	49.0
2:09	355	91.1	-23.1	-0.9	67.1	40.9
2:12	395	91.1	-35.4	-1.4	54.3	40.0
2:16	435	91.1	-52.0	-2.1	37.3	32.4
2:23	475	91.1	-74.0	-3.0	14.1	15.0
2:30	495	91.1	-87.3	-3.6	0.2	0
2:32	495	0	-87.3	-3.6	-90.9	-71.3
2:33	475	0	-74.0	-3.0	-77.0	-55.3
2:37	435	0	-52.0	-2.1	-54.1	-28.8
2:42	395	0	-35.4	-1.4	-36.8	-20.0
2:50	395	0	-23.1	-0.9	-24.0	-11.8
3:02	320	0	-15.2	-0.5	-15.7	-5.8

THERMAL MANEUVER AVERAGE RATE $= \frac{-23.3}{14} = -1.66$ BTU/HR-FT²
(SHIELD-TO-ADAPTER)


STUB ADAPTER HEATING HISTORY TO LH_2
HEAT RATE, BTU/HR
BTU/HR
10000
5000
0
1000
500
MECO
1
2
3
4
TOTAL
METALLIC CONDUCTION
CREVICE HEAT TRANSFER
0
100
200
300
50
100
150
200
250
300
SECONDS
MINUTES
TIME FROM LIFT-OFF

THERMAL AND HEAT TRANSFER

- PRELAUNCH THERMAL CONTROL BY GAS CONDITIONING AND PURGING
- PRELAUNCH TANK HEATING
- ASCENT THERMAL ENVIRONMENT AND RESPONSE
- SPACE AND VEHICLE INDUCED ENVIRONMENT
- FORWARD BULKHEAD MULTILAYER INSULATION
  - — THERMAL RESPONSE AND PERFORMANCE
- THREE-LAYER SHIELDING
  - — THERMAL RESPONSE AND PERFORMANCE
- TITANIUM STUB ADAPTER AND GROUND PLANE/SHIELD
  - — THERMAL RESPONSE AND PERFORMANCE
- WIRING MODULE STRUCTURE/TYPICAL PENETRATION
  - — THERMAL RESPONSE AND PERFORMANCE
- LH_2 TANK FLIGHT HEAT RATES

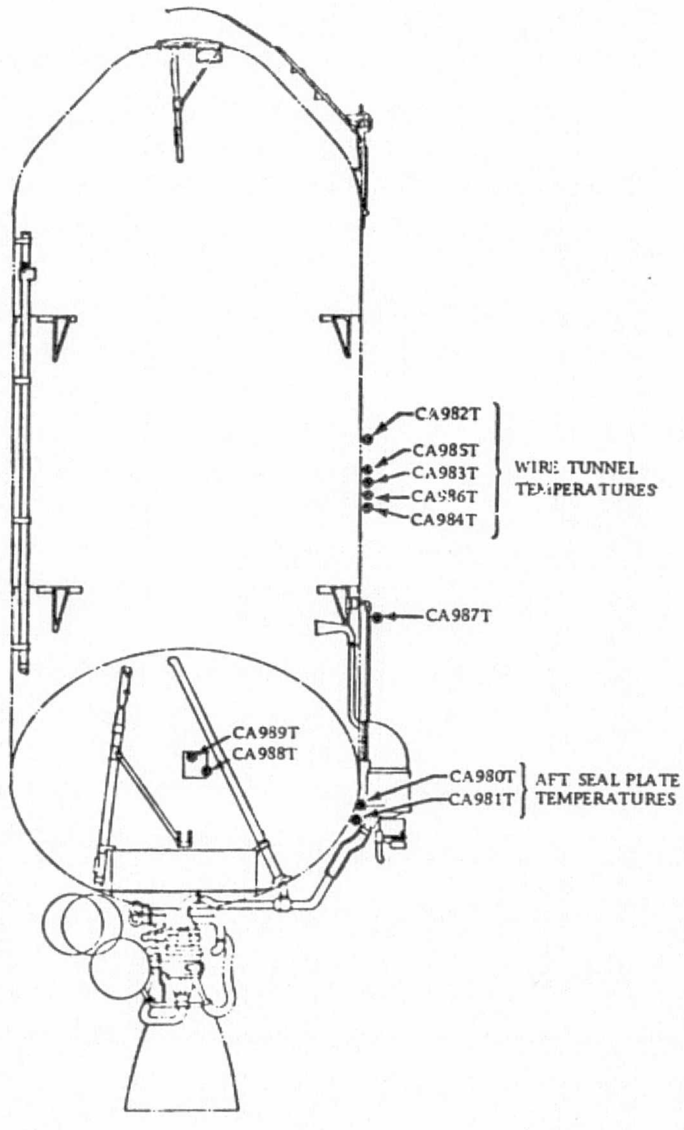
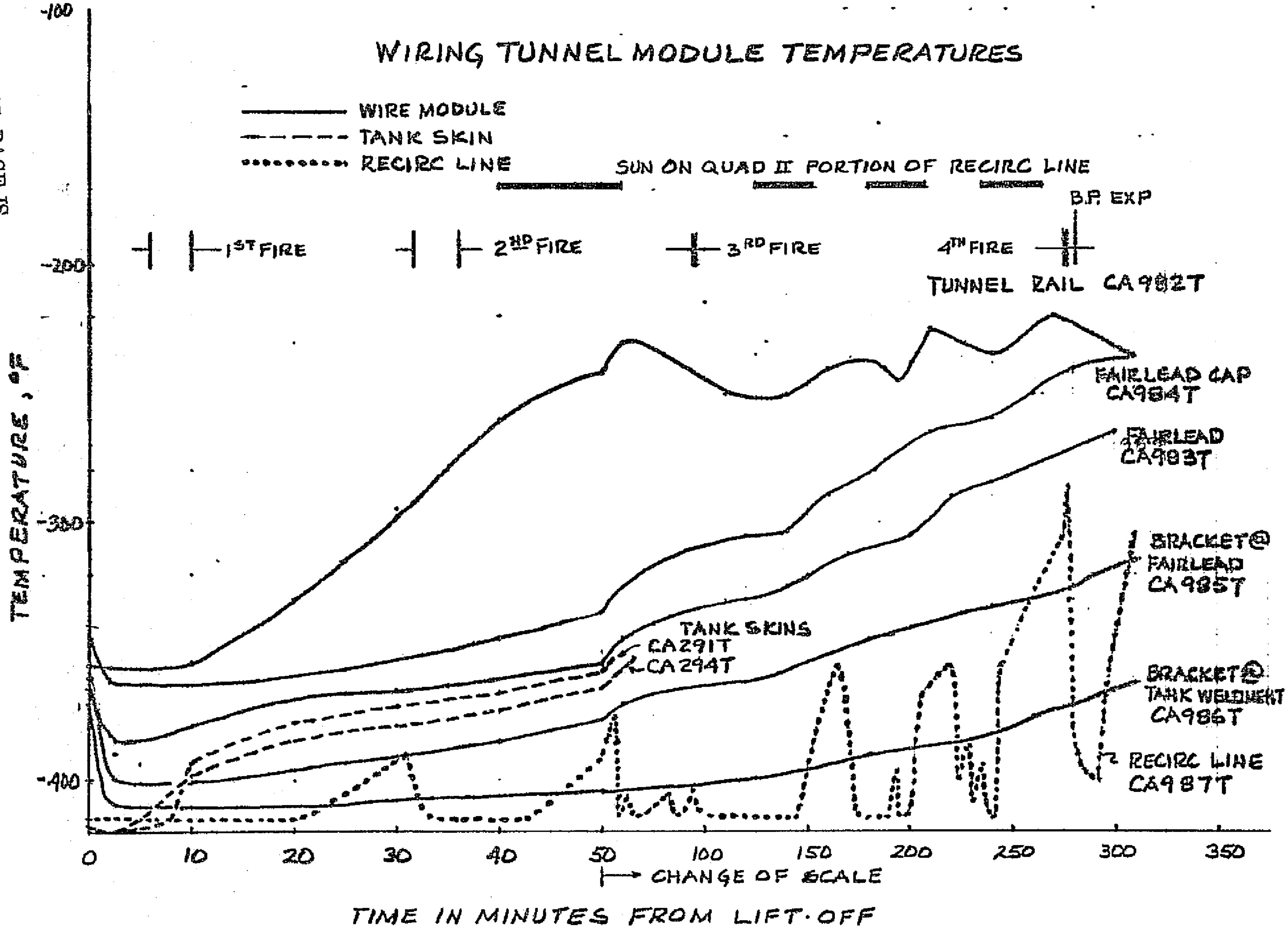


Figure Wire tunnel and aft seal plate temperature measurements.



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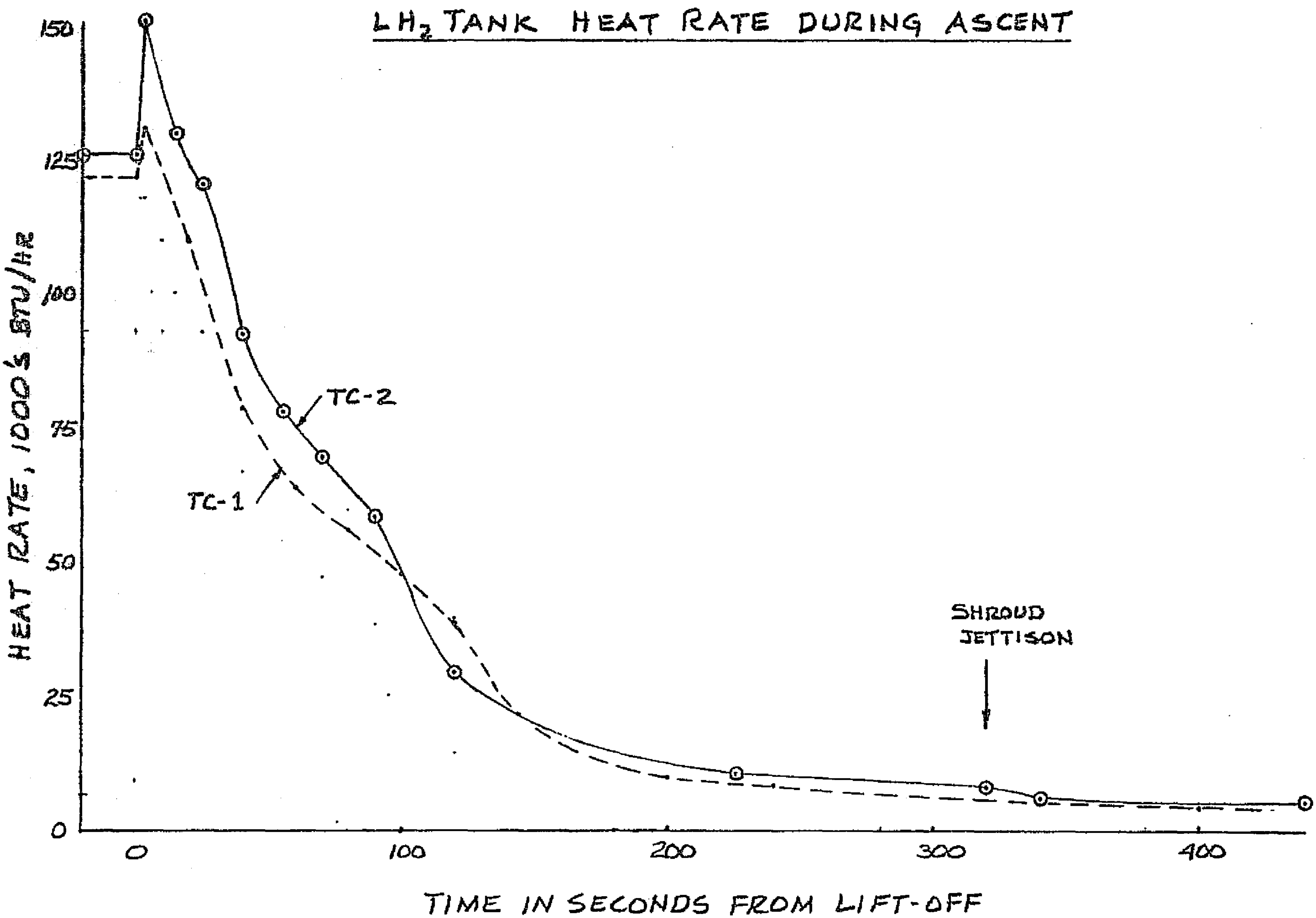
THERMAL AND HEAT TRANSFER

- PRELAUNCH THERMAL CONTROL BY GAS CONDITIONING AND PURGING
- PRELAUNCH TANK HEATING
- ASCENT THERMAL ENVIRONMENT AND RESPONSE
- SPACE AND VEHICLE INDUCED ENVIRONMENT
- FORWARD BULKHEAD MULTILAYER INSULATION
  - — THERMAL RESPONSE AND PERFORMANCE
- THREE-LAYER SHIELDING
  - — THERMAL RESPONSE AND PERFORMANCE
- TITANIUM STUB ADAPTER AND GROUND PLANE/SHIELD
  - — THERMAL RESPONSE AND PERFORMANCE
- WIRING MODULE STRUCTURE/TYPICAL PENETRATION
  - — THERMAL RESPONSE AND PERFORMANCE
- LH_2 TANK FLIGHT HEAT RATES



LH2 TANK HEAT RATE DURING ASCENT
HEAT RATE, 1000's BTU/HR
150
125
100
75
50
25
0
TC-2
TC-1
SHROUD JETTISON
0
100
200
300
400
TIME IN SECONDS FROM LIFT-OFF

TABLE 7-X. SUMMARY OF LH_2 TANK AVERAGE HEAT RATES DURING COASTS (Btu/HR).

CONTRIBUTING AREA	COAST FIRST 584-1900 SEC	COAST SECOND 2173-5773 SEC	COAST THIRD 5784-16584 SEC
FORWARD BULKHEAD AFT TO S/A MIDFRAME	115	50	80
CREVICE FORWARD TO S/A MIDFRAME	150	110	75
STUB ADAPTER (S/A)/RING	600	285	245
SIDE WALL SHIELDING	80	125	330
WIRING TUNNEL MODULE	36	29	43
RECIRCULATION LINE	110	80	40
SUMP FWD OF BULKHEAD	5	5	4
SUMP/BLKHD ATTACHMENT	13	15	10
SUMP AFT OF BULKHEAD	61	48	47
LH_2 BOOST PUMP	50	67	57
FEED LINES	176	82	40
MAIN VALVES	12	12	15
DESTRUCTOR	75	62	32
H_2 VENT VALVES	30	70	120
H_2 VENT DUCTS	8	8	10
LH_2 PRESSURE SENSE LINES	3	5	6
FWD DOOR HARNESSES	7	11	8
HELIUM DIFFUSER	110	65	28
LH_2 FILL AND DRAIN PORT	19	9	18
SEAL PLATE SUPPORT STRUTS	60	36	29
TOTAL LH_2 TANK INPUT LESS INT. BLKHD	1720	1174	1237

THERMAL AND HEAT TRANSFER

- LO_2 TANK SHIELD INSULATION KIT
  - THERMAL RESPONSE AND LO_2 TANK FLIGHT HEAT RATES
- INTERMEDIATE BULKHEAD PERFORMANCE FROM PROPELLANT ENERGY BALANCES
- TANK VENT SYSTEMS
  - THERMAL RESPONSE
- ELECTRONIC EQUIPMENT
  - THERMAL RESPONSE AND PERFORMANCE
- HYDRAULIC SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE
- H_2O_2 SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE
- H_2O_2 SYSTEM EXHAUST IMPINGEMENT HEATING ENVIRONMENT
- MAIN PROPULSION SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE
- THERMAL CONTROL SUMMARY

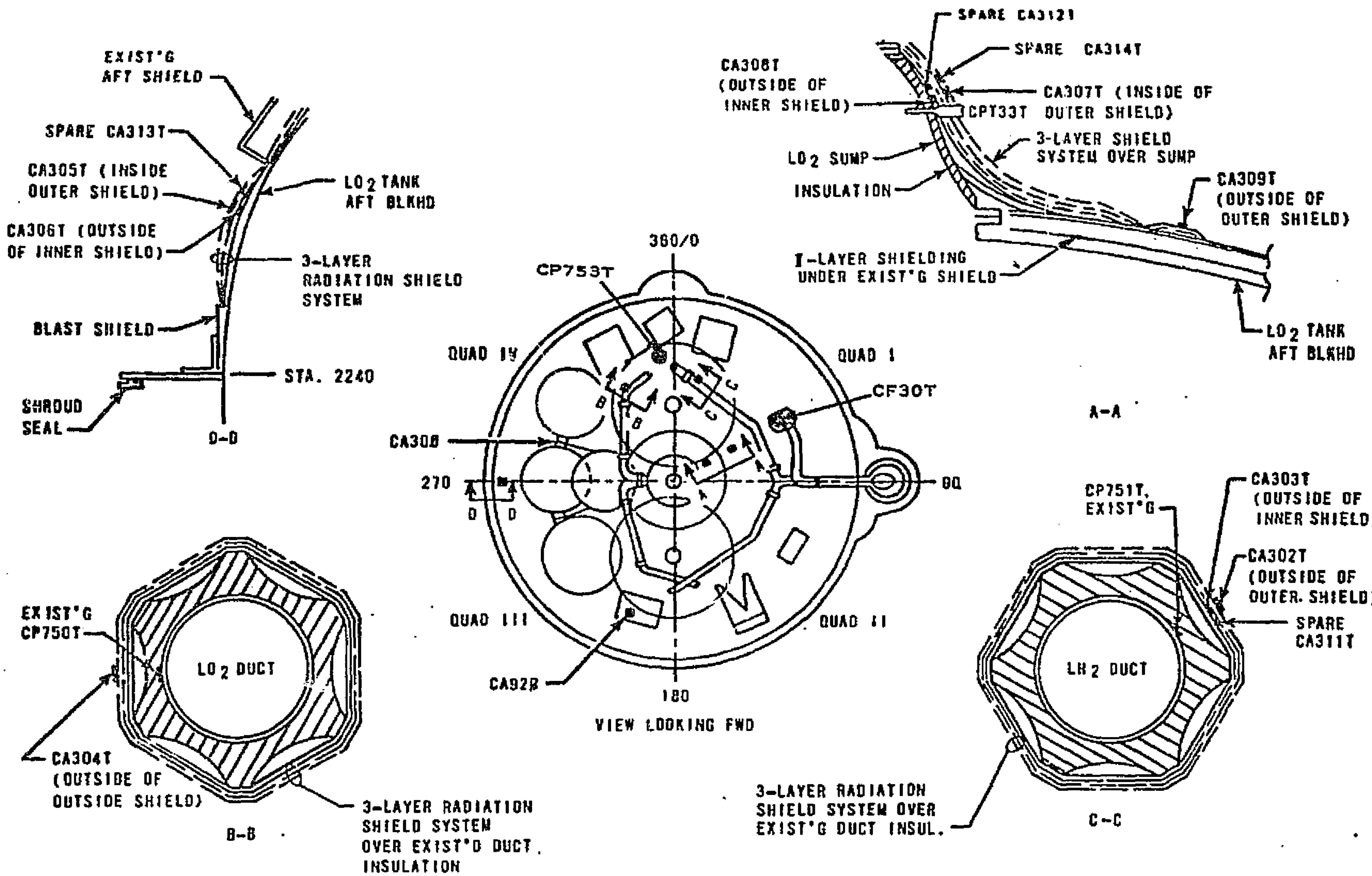
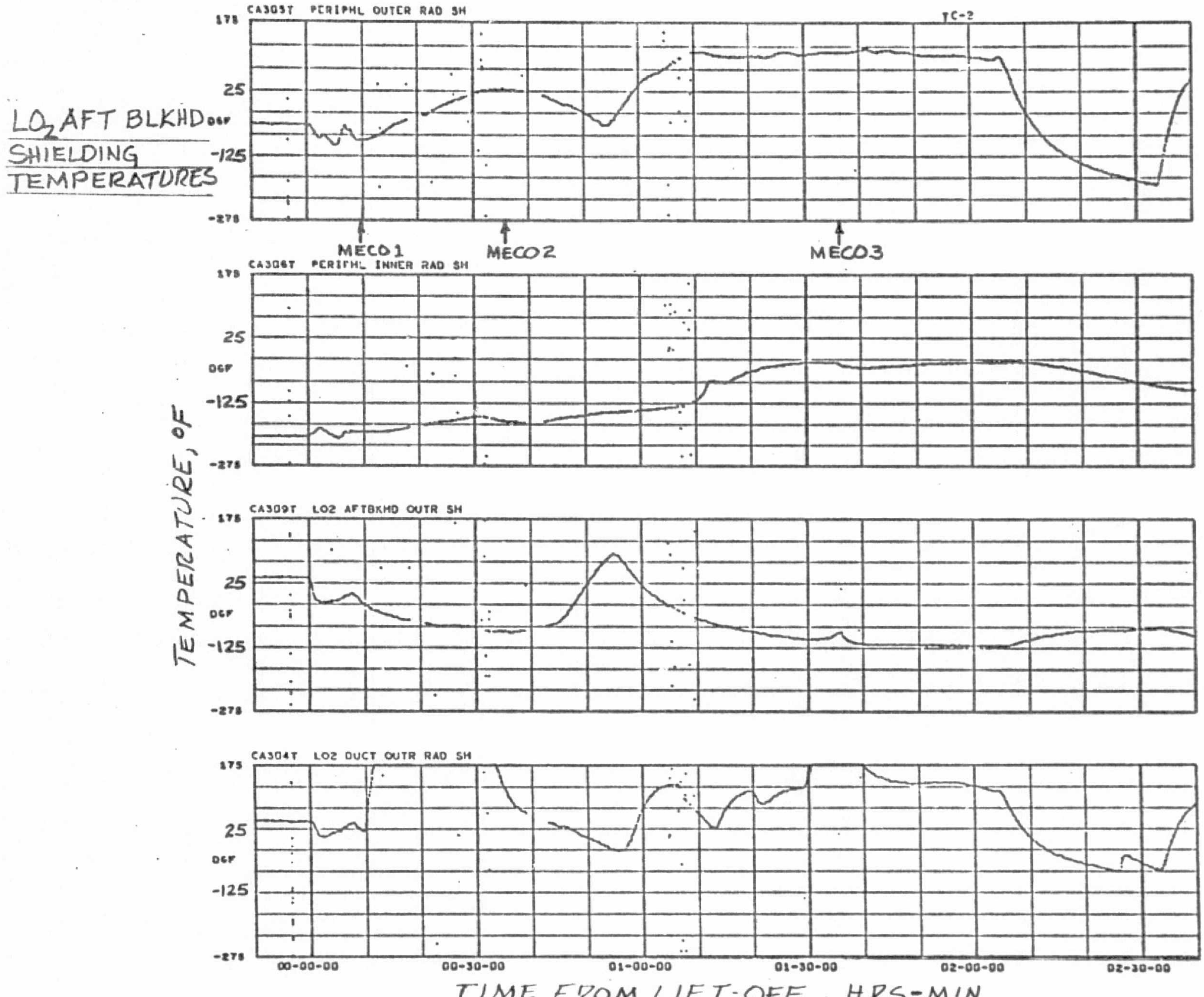
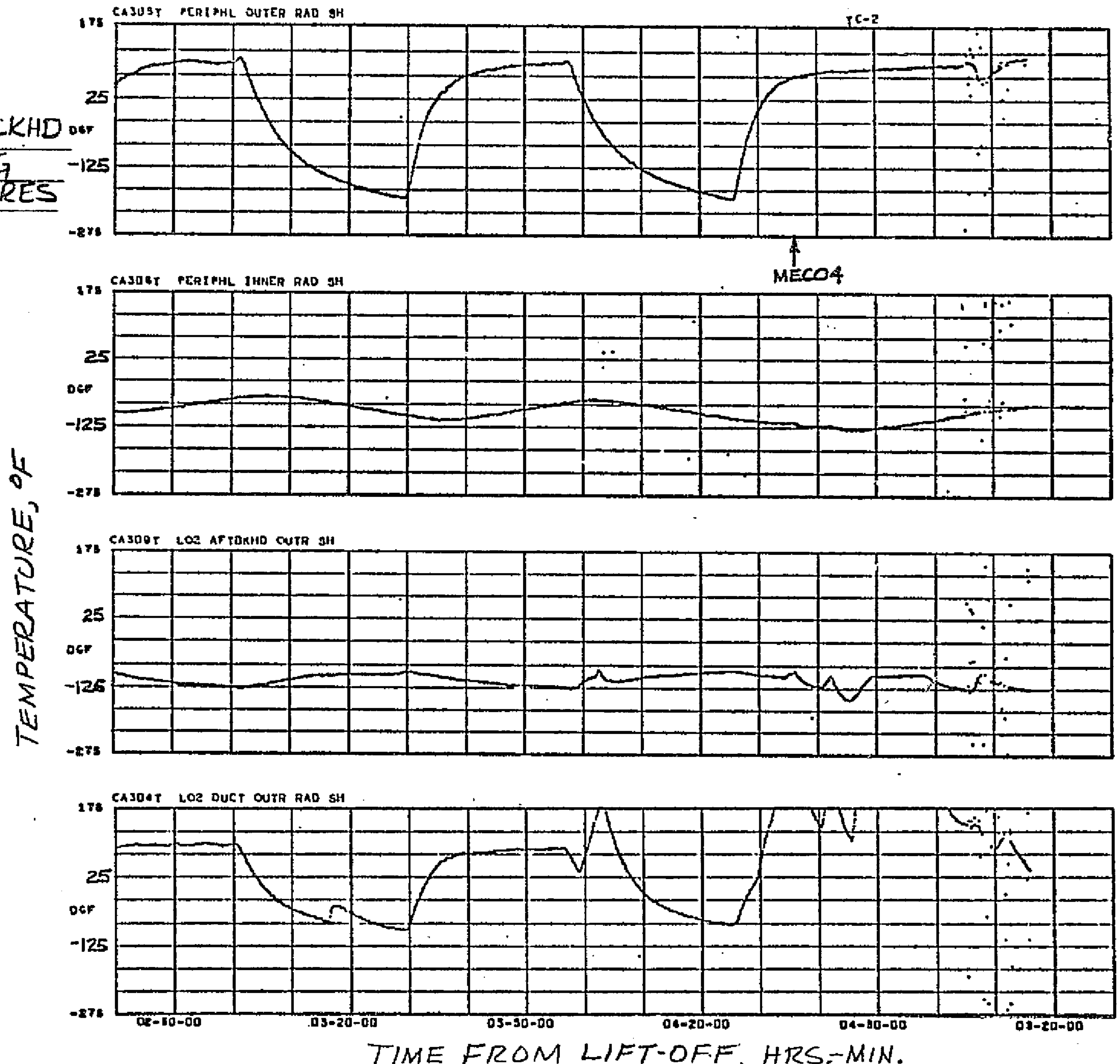


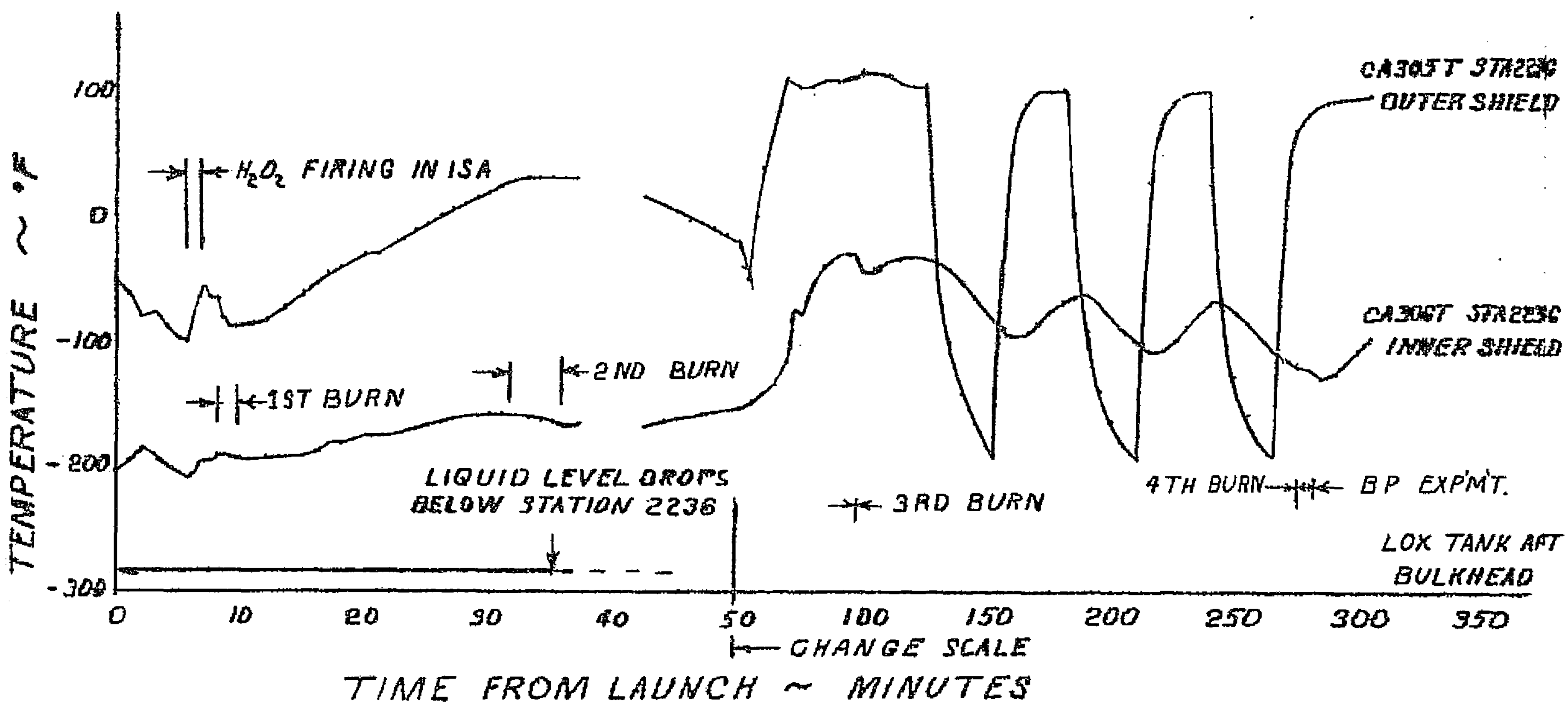
Figure Thrust section radiation shield temperature instrumentation.

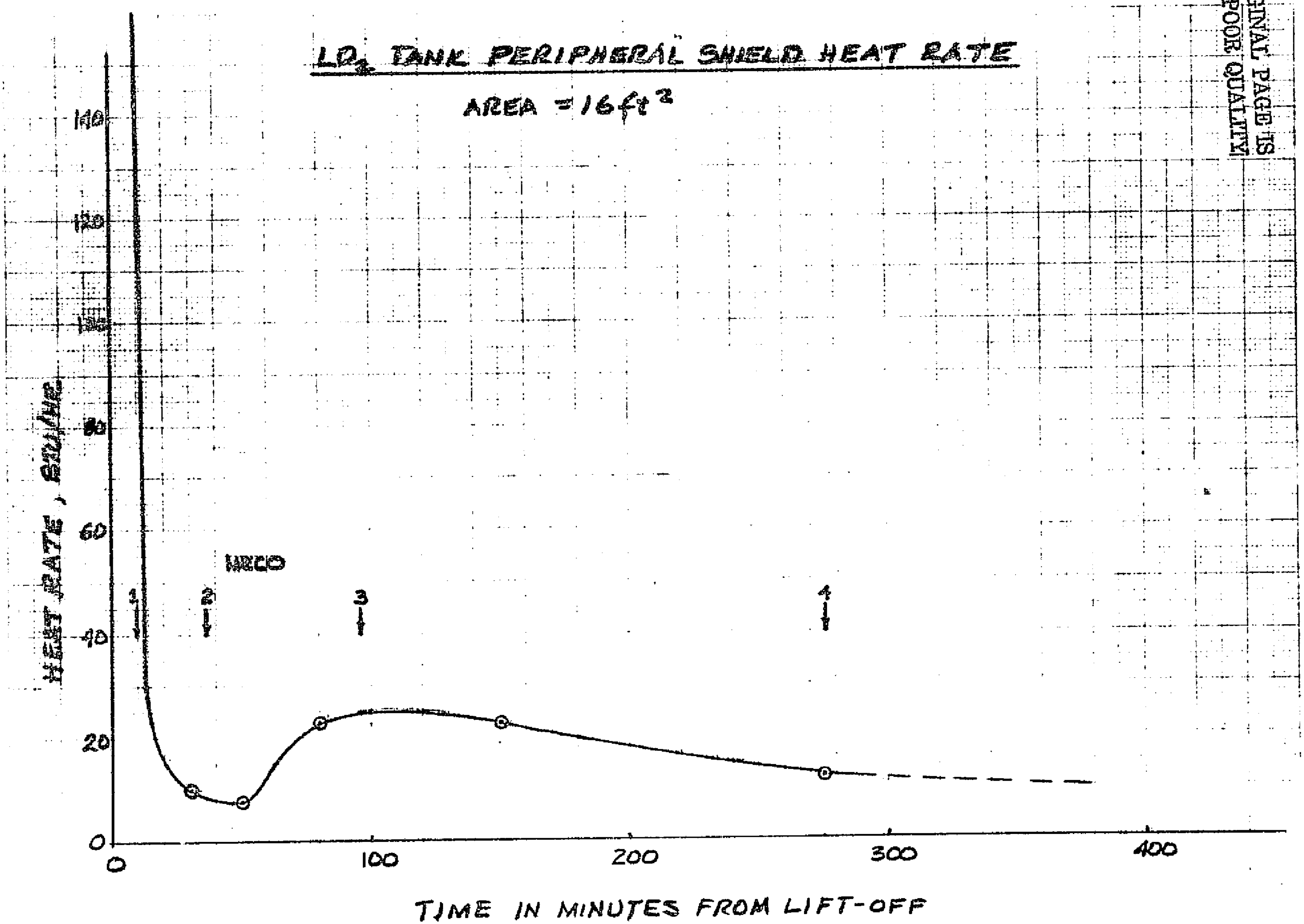

LO2 AFT BLKHD SHIELDING TEMPERATURES
CA305T PERIPHL OUTER RAD SH
TC-2
MECO1
MECO2
MECO3
CA306T PERIPHL INNER RAD SH
CA309T LO2 AFTBKHD OUTR SH
CA304T LO2 DUCT OUTR RAD SH
175
25
0°F
-125
-275
TEMPERATURE, °F
00-00-00
00-30-00
01-00-00
01-30-00
02-00-00
02-30-00
TIME FROM LIFT-OFF, HRS.-MIN.

LO_2 AFT BLKHD SHIELDING TEMPERATURES (CONT)



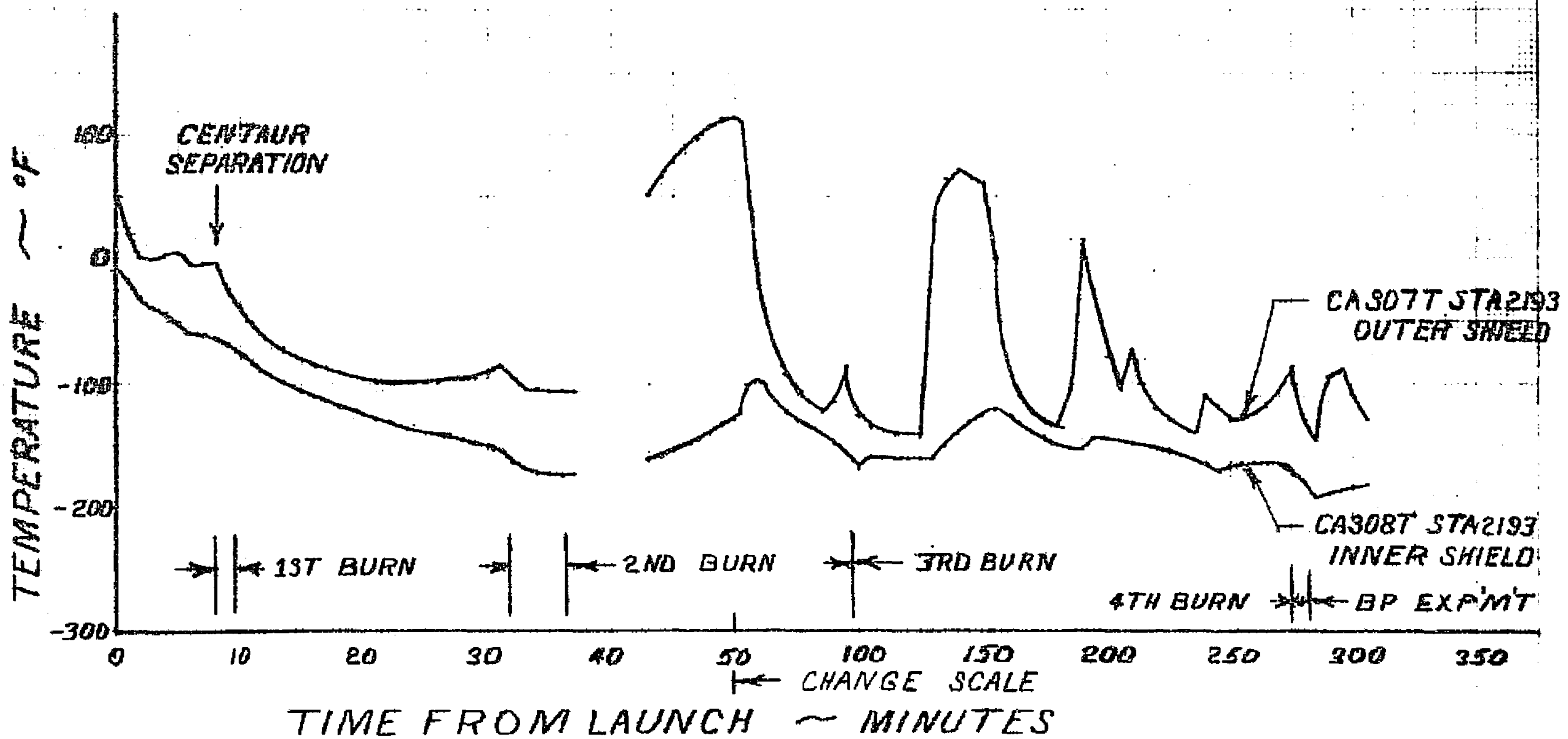
LOX TANK PERIPHERAL RADIATION SHIELD
TEMPERATURE PROFILE
STATION 2236 @ 270°

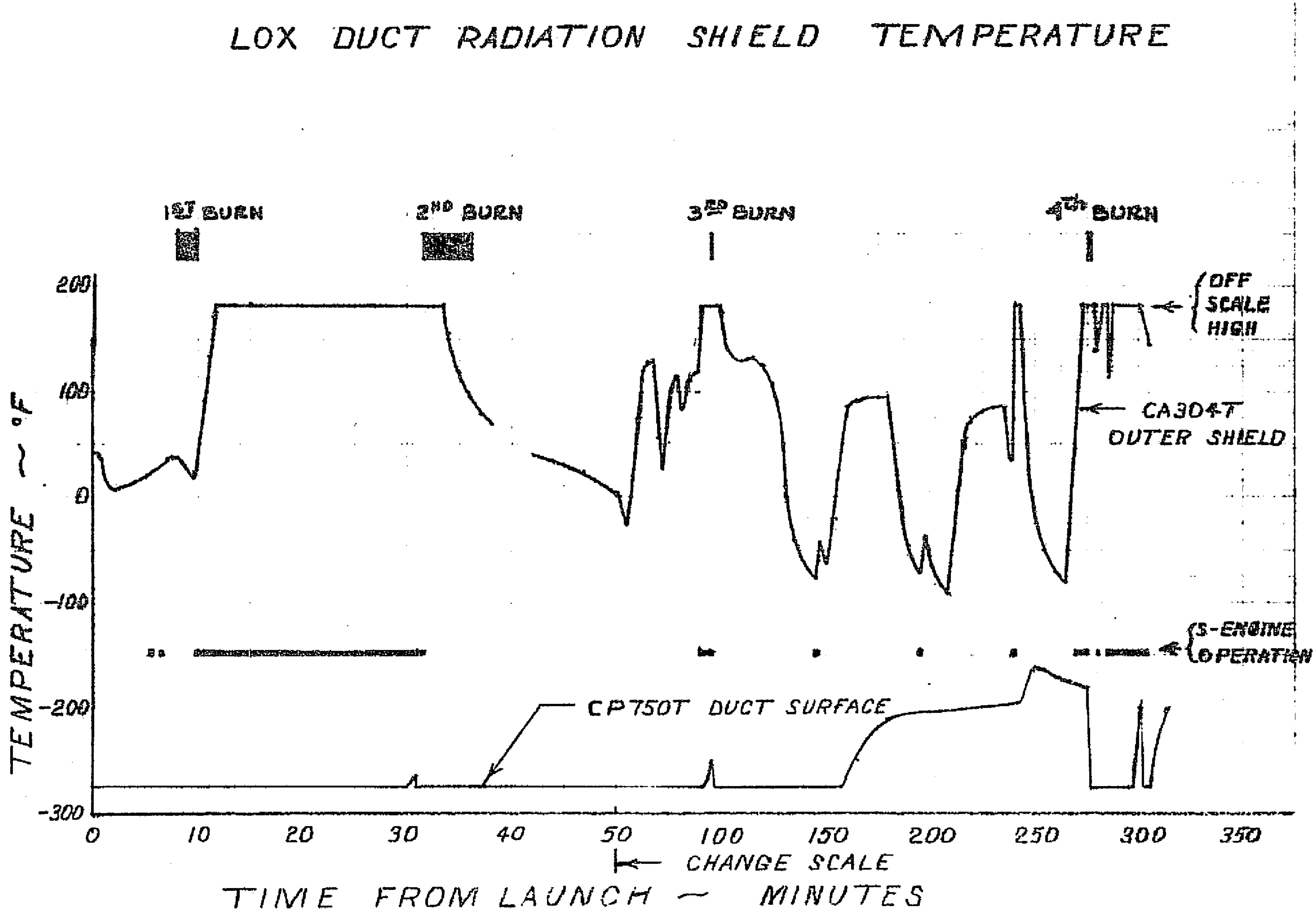



LO2 TANK PERIPHERAL SHIELD HEAT RATE
AREA = 16 ft²
HEAT RATE, BTU/HR
140
120
80
60
40
20
0
MECO
1
2
3
4
0
100
200
300
400
TIME IN MINUTES FROM LIFT-OFF

LOX SUMP RADIATION SHIELD TEMPERATURE PROFILE

STATION 2193 @ 60°




LOX DUCT RADIATION SHIELD TEMPERATURE
1ST BURN
2ND BURN
3RD BURN
4TH BURN
OFF SCALE HIGH
CA304T OUTER SHIELD
S-ENGINE OPERATION
CP750T DUCT SURFACE
TEMPERATURE ~ °F
200
100
0
-100
-200
-300
0
10
20
30
40
50
100
150
200
250
300
350
CHANGE SCALE
TIME FROM LAUNCH ~ MINUTES

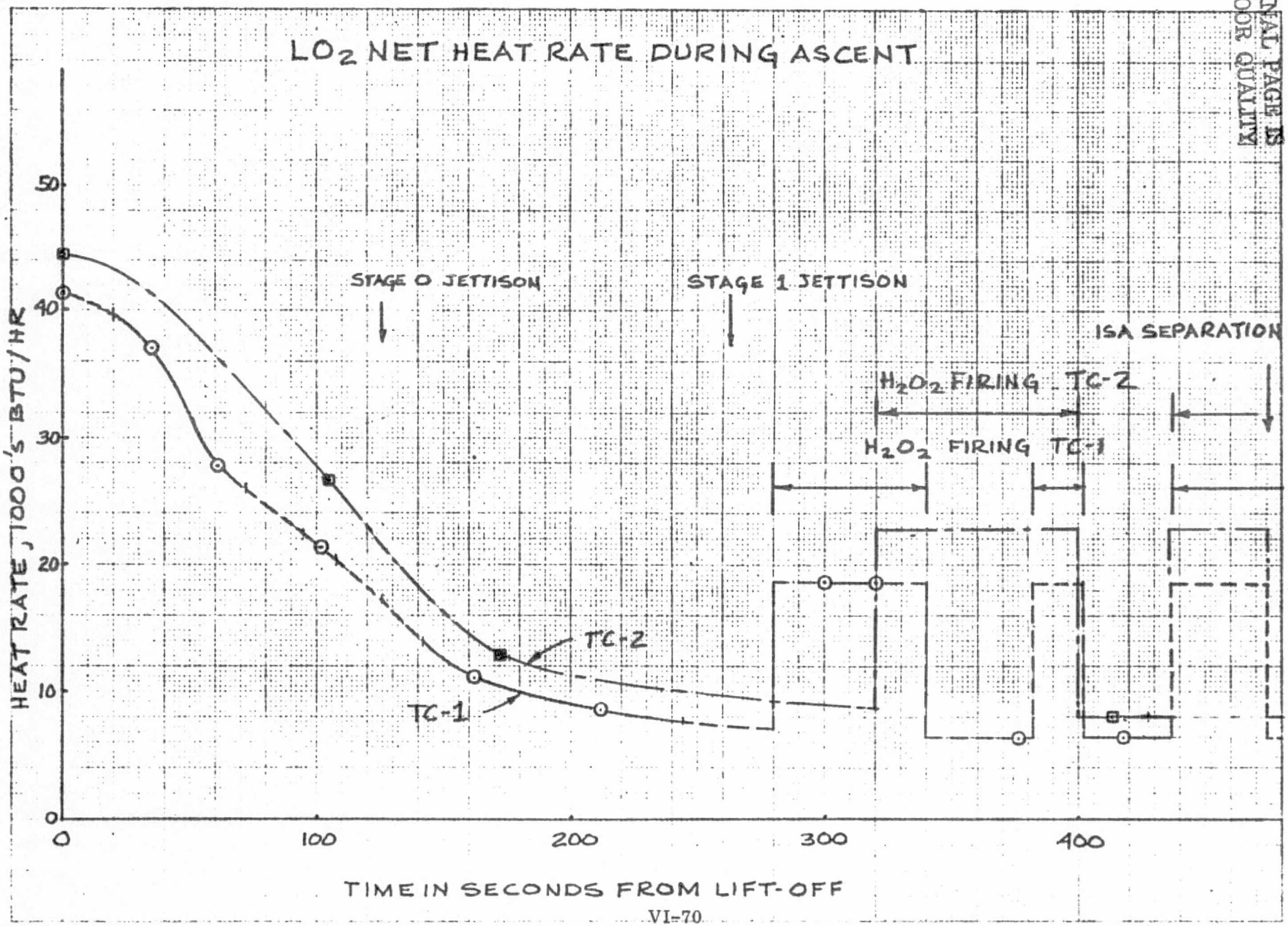


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FIGURE

TABLE 7-XI. SUMMARY OF LO_2 TANK AVERAGE HEATING RATES DURING COASTS (Btu/HR).

CONTRIBUTING AREA	COAST FIRST 584-1900 SEC		COAST SECOND 2173-5773 SEC		COAST THIRD 5784-16584 SEC	
CYLINDRICAL SECTION 2.75" HIGH	9		6		11	
2240 RING	961		428		203	
WIRING TUNNEL AFT BULKHEAD	61		35		15	
3" HIGH BARE PERIPHERAL AREA	440		363		310	
6" HIGH 3-SHIELD INSULATED AREA	24		17		20	
FIXED/LEAKAGE SHIELDS OUTSIDE THRUST BARREL (BASIC)	232		473		231	
BASE GAS BACK-FLOW DEGRADATION	157		62		9	
EQUIP. CONDUCTION OUTSIDE THRUST BARREL	1231		1162		835	
TOTAL OUTSIDE THRUST BARREL		3115		2546		1634
FIXED/LEAKAGE SHIELDS INSIDE THRUST BARREL (BASIC)	29		60		29	
BASE GAS BACK-FLOW DEGRADATION	19		8		1	
EQUIP. CONDUCTION BETWEEN SUMP & THRUST BARREL	254		260		206	
TOTAL BETWEEN SUMP & THRUST BARREL		302		328		236
SUMP W/3-LAYER SHIELD BOOT	116		64		40	
EQUIP. CONDUCTION TO SUMP	98		73		34	
BOOST PUMP CONDUCTION TO SUMP	103		150		120	
TOTAL SUMP		317		287		194
FEED LINES AND LO_2 BLEED LINE	94		117		77	
MAIN VALVES	122		59		62	
TOTAL LINES & VALVES		216		176		139
TOTAL LO_2 TANK INPUT (INT. BULKHEAD EFFECT NOT INCLUDED)		3950		3337		2203

THERMAL AND HEAT TRANSFER

- LO_2 TANK SHIELD INSULATION KIT
  - THERMAL RESPONSE AND LO_2 TANK FLIGHT HEAT RATES
- INTERMEDIATE BULKHEAD PERFORMANCE FROM PROPELLANT ENERGY BALANCES
- TANK VENT SYSTEMS
  - THERMAL RESPONSE
- ELECTRONIC EQUIPMENT
  - THERMAL RESPONSE AND PERFORMANCE
- HYDRAULIC SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE
- H_2O_2 SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE
- H_2O_2 SYSTEM EXHAUST IMPINGEMENT HEATING ENVIRONMENT
- MAIN PROPULSION SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE
- THERMAL CONTROL SUMMARY

PROPELLANT HEATING AGREES WITH PREDICTIONS*

	PRELAUNCH			1ST COAST			2ND COAST			3RD COAST		
	MAX	NOM	MIN	MAX	NOM	MIN	MAX	NOM	MIN	MAX	NOM	MIN
LH_2 TANK												
PREDICTED												
EXTERNAL				2700	1570	833	2085	1404	717	1671	1174	737
INT. BLKHD				1541	1233	924	1045	710	605	1045	710	605
TOTAL	132,020	120,445	100,844	4241	2803	1757	3130	2114	1322	2716	1884	1342
MEASURED TOTAL		126,450	BY BOILOFF		2953			2270			2270	
LO_2 TANK												
PREDICTED												
EXTERNAL				5098	3424	2497	2972	1987	1479	2689	1970	1252
INT. BLKHD.				924	1233	1542	605	710	1045	605	710	1045
NET	49,400	43,346	36,785	4174	2191	955	2367	1277	434	2084	1260	207
MEASURED NET		48,300 44,370	BY BOILOFF BY ISA ENERGY BAL.		2717			2403			1077	

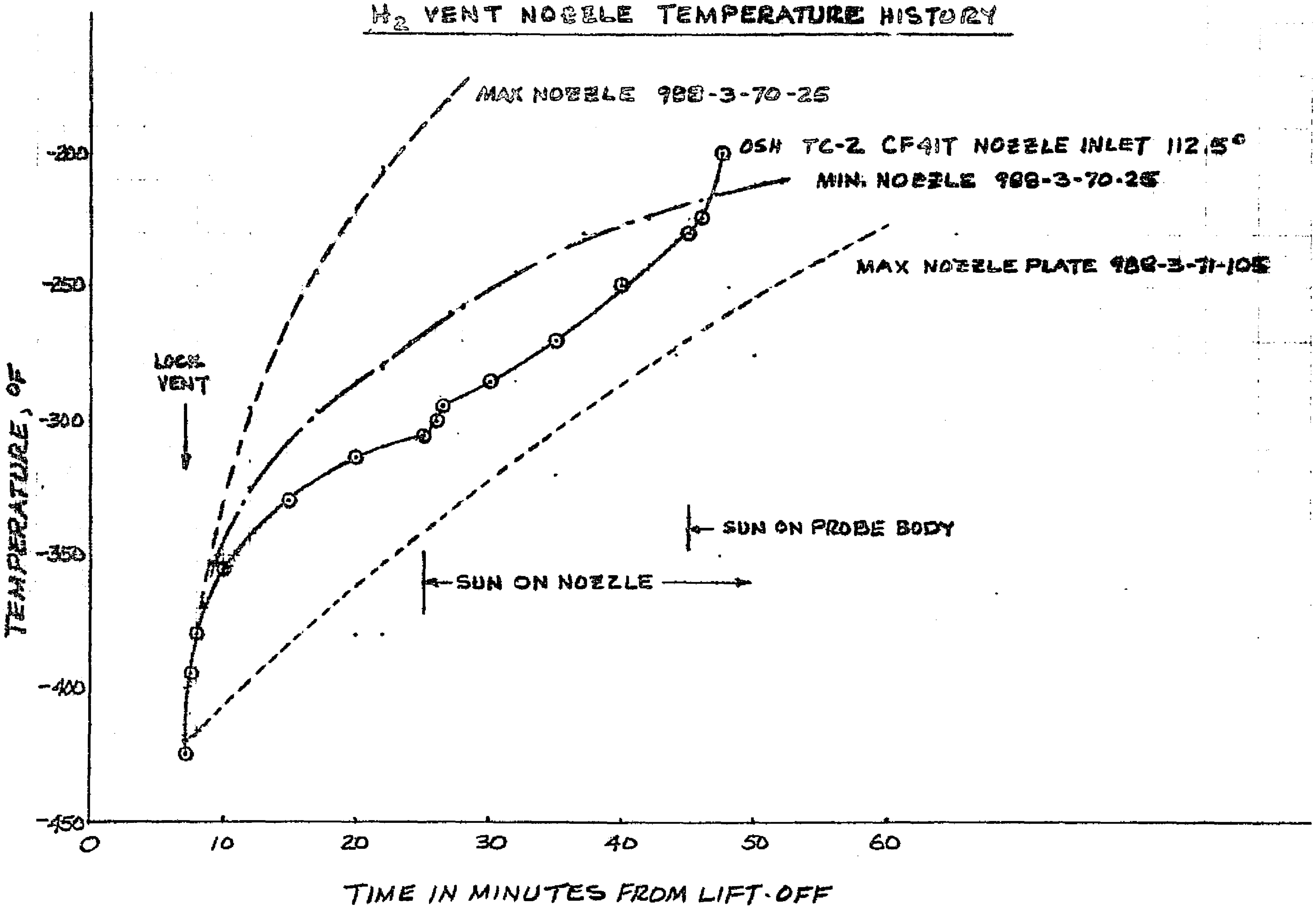
*PREDICTIONS FROM 965-4/HT72/025 WITH 22-MINUTE FIRST COAST INTERPOLATED BETWEEN 12- AND 30-MINUTE COAST PREDICTIONS

TABLE 7-XII. INDICATED INTERMEDIATE BULKHEAD HEAT TRANSFER RATE DURING SPACE OPERATIONS (Btu/HR).

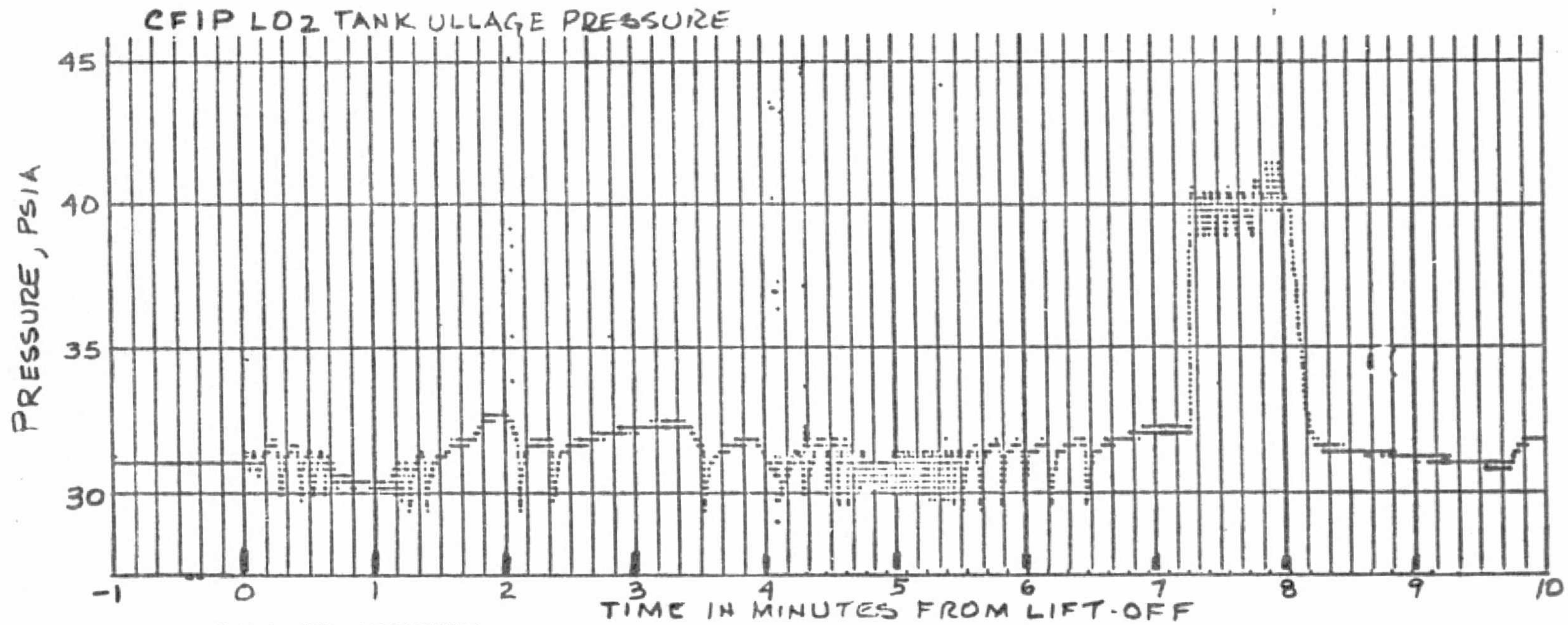
	COAST		
	FIRST	SECOND	THIRD
LH_2 TANK			
TOTAL HEAT INPUT FROM H_2 ENERGY AND MASS BALANCE		2270	2270
SUMMATION OF EXTERNAL HEAT INPUTS	1720	1174	1237
INDICATED INTERMEDIATE BULKHEAD HEAT RATE		1096	933
LO_2 TANK			
NET HEAT INPUT FROM O_2 ENERGY AND MASS BALANCE		2403	1077
SUMMATION OF EXTERNAL HEAT INPUTS	3950	3337	2203
INDICATED INTERMEDIATE BULKHEAD HEAT RATE		-934	-1126
INTERMEDIATE BULKHEAD HEAT RATE RANGE		1015 ± 81	1030 ± 97
PREDICTED RANGE FOR LH_2 WET JOINT CREVICE		1233 ± 309	1233 ± 309
PREDICTED RANGE FOR LH_2 DRY JOINT CREVICE		710^{+335}_{-105}	710^{+335}_{-105}

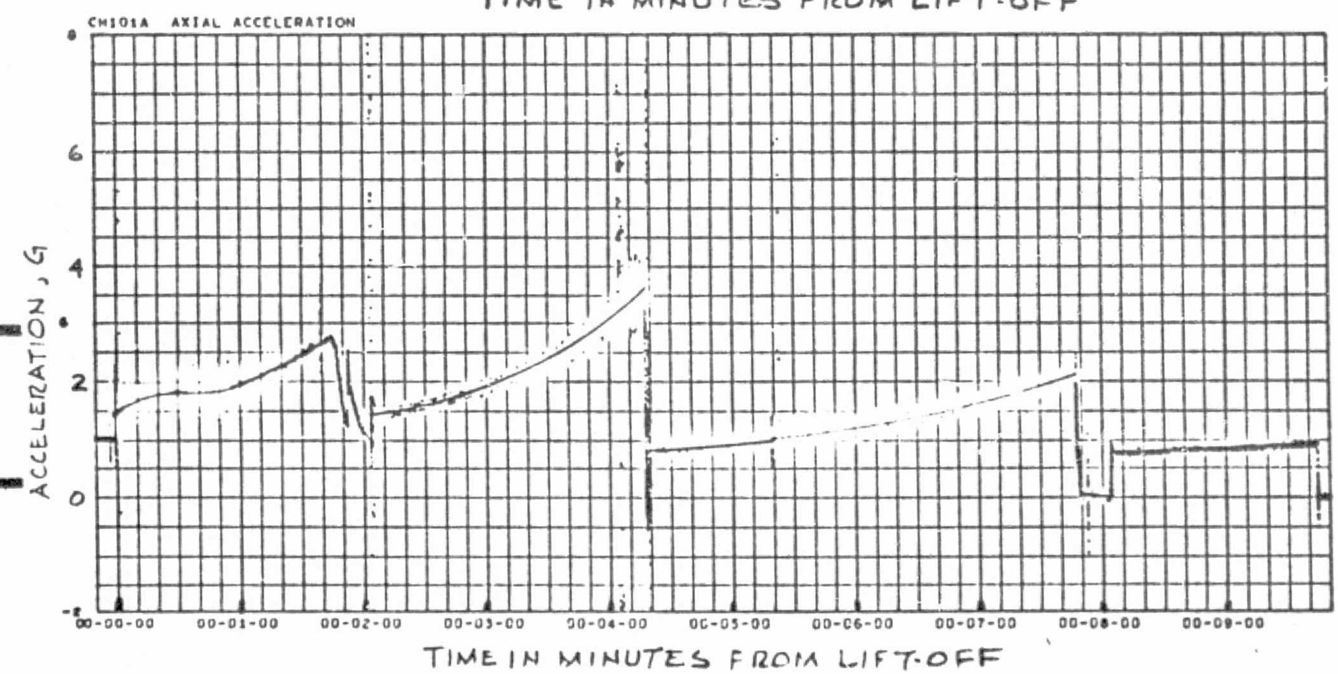
THERMAL AND HEAT TRANSFER

- LO_2 TANK SHIELD INSULATION KIT
  - — THERMAL RESPONSE AND LO_2 TANK FLIGHT HEAT RATES
- INTERMEDIATE BULKHEAD PERFORMANCE FROM PROPELLANT ENERGY BALANCES
- TANK VENT SYSTEMS
  - — THERMAL RESPONSE
- ELECTRONIC EQUIPMENT
  - — THERMAL RESPONSE AND PERFORMANCE
- HYDRAULIC SYSTEM
  - — THERMAL RESPONSE AND PERFORMANCE
- H_2O_2 SYSTEM
  - — THERMAL RESPONSE AND PERFORMANCE
- H_2O_2 SYSTEM EXHAUST IMPINGEMENT HEATING ENVIRONMENT
- MAIN PROPULSION SYSTEM
  - — THERMAL RESPONSE AND PERFORMANCE
- THERMAL CONTROL SUMMARY

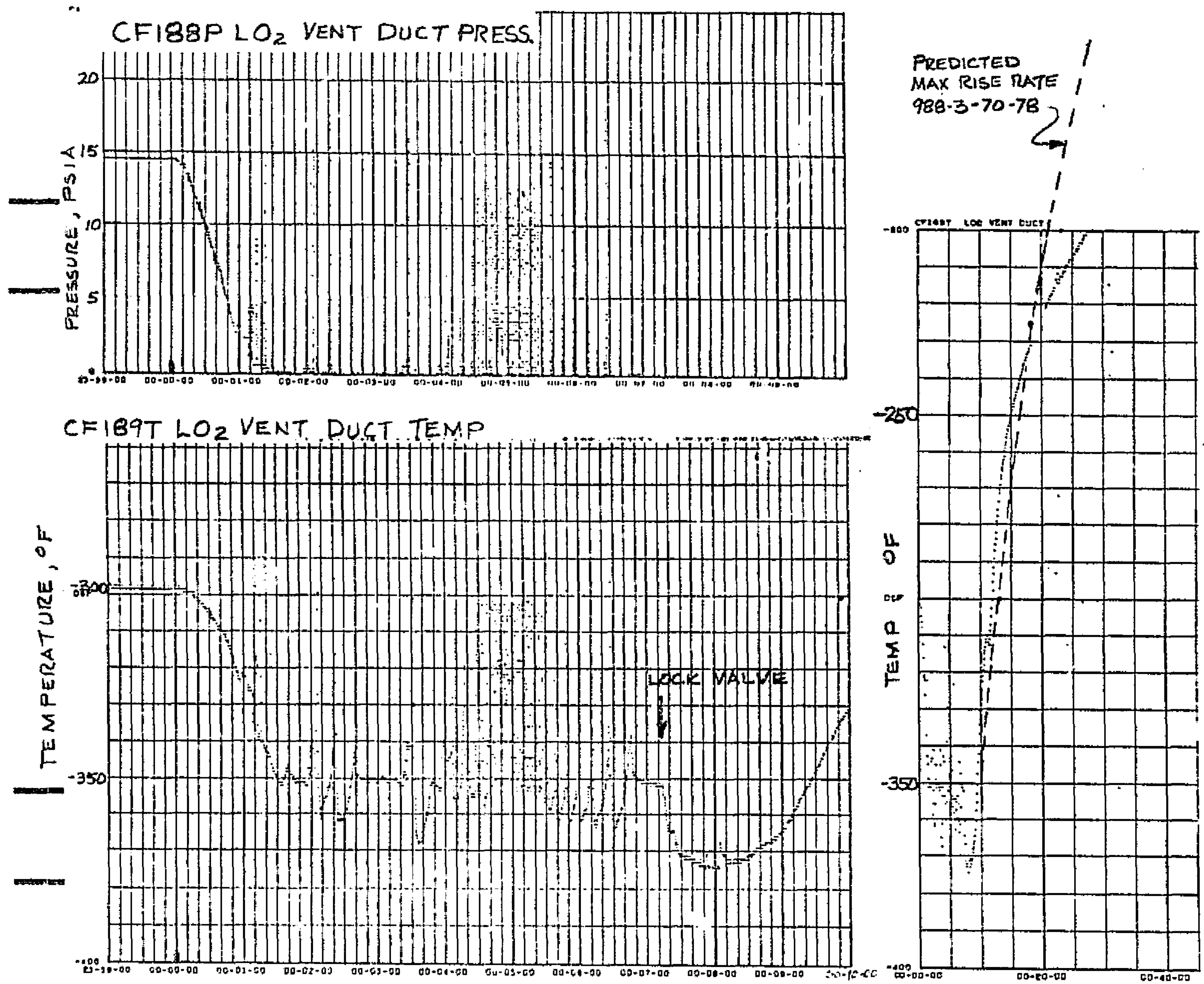

H2 VENT NOZZLE TEMPERATURE HISTORY
MAX NOZZLE 988-3-70-25
OSH TC-2 CF41T NOZZLE INLET 112.5°
MIN. NOZZLE 988-3-70-25
MAX NOZZLE PLATE 988-3-71-105
LOCK VENT
SUN ON PROBE BODY
SUN ON NOZZLE
TEMPERATURE, °F
-200
-250
-300
-350
-400
-450
0
10
20
30
40
50
60
TIME IN MINUTES FROM LIFT-OFF

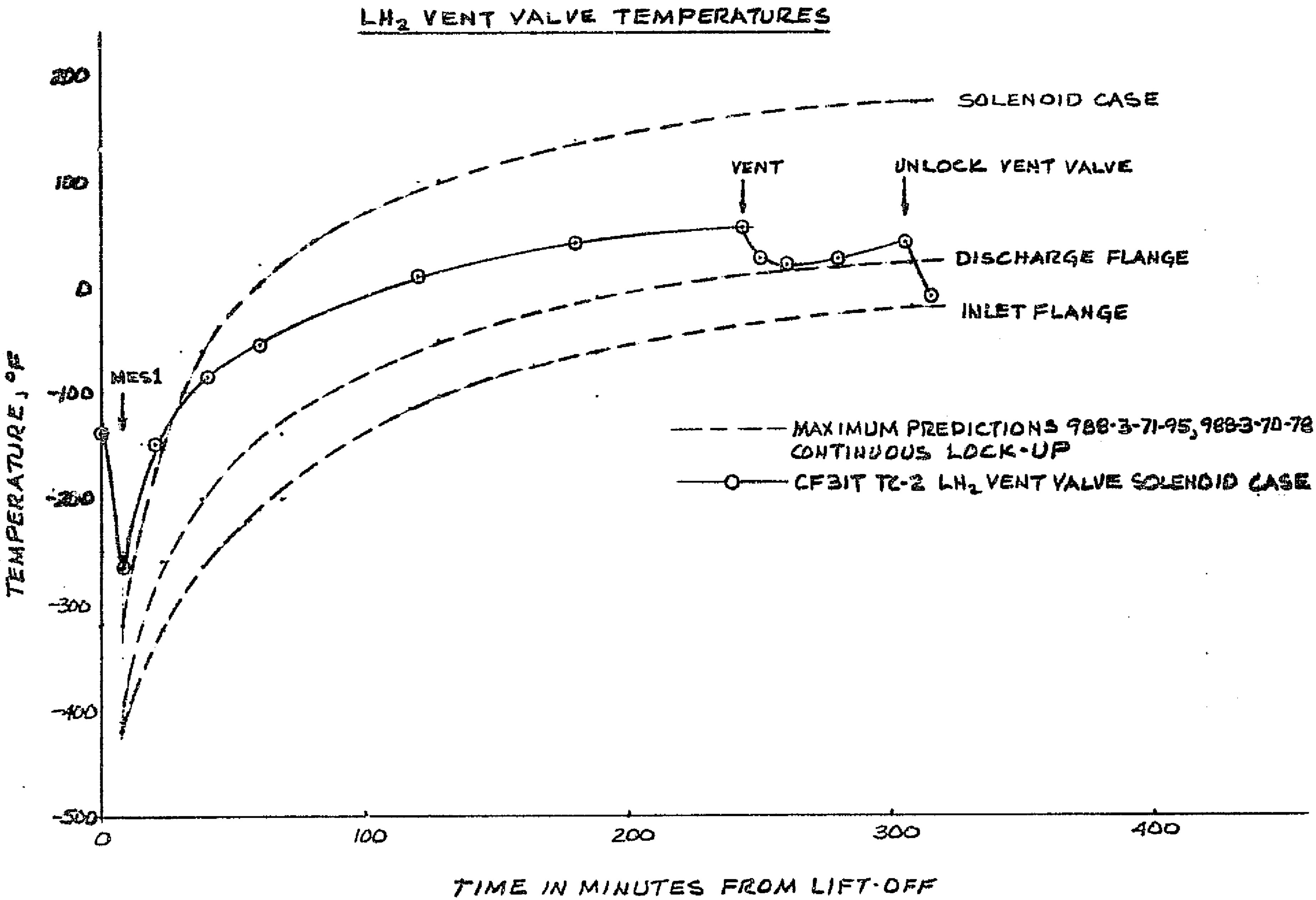
VEHICLE ACCELERATION & LO_2 TANK ULLAGE PRESSURE



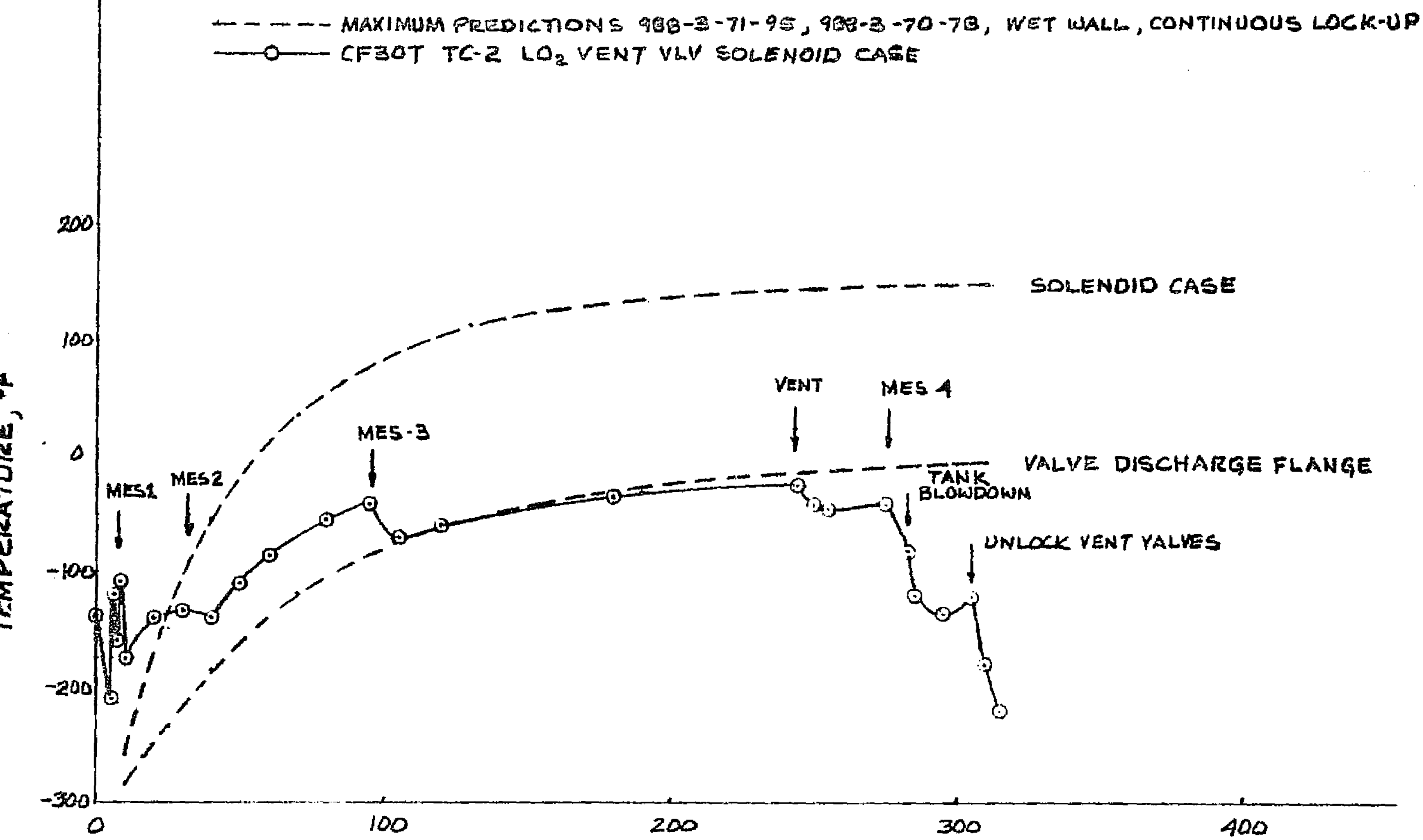


LO2 VENT DUCT PRESSURE AND TEMPERATURE




LH$_2$ VENT VALVE TEMPERATURES
SOLENOID CASE
VENT
UNLOCK VENT VALVE
DISCHARGE FLANGE
INLET FLANGE
MES1
MAXIMUM PREDICTIONS 988-3-71-95, 988-3-70-78
CONTINUOUS LOCK-UP
CF31T TC-2 LH$_2$ VENT VALVE SOLENOID CASE
TEMPERATURE, °F
200
100
0
-100
-200
-300
-400
-500
0
100
200
300
400
TIME IN MINUTES FROM LIFT-OFF

LO$_2$ VENT VALVE TEMPERATURES

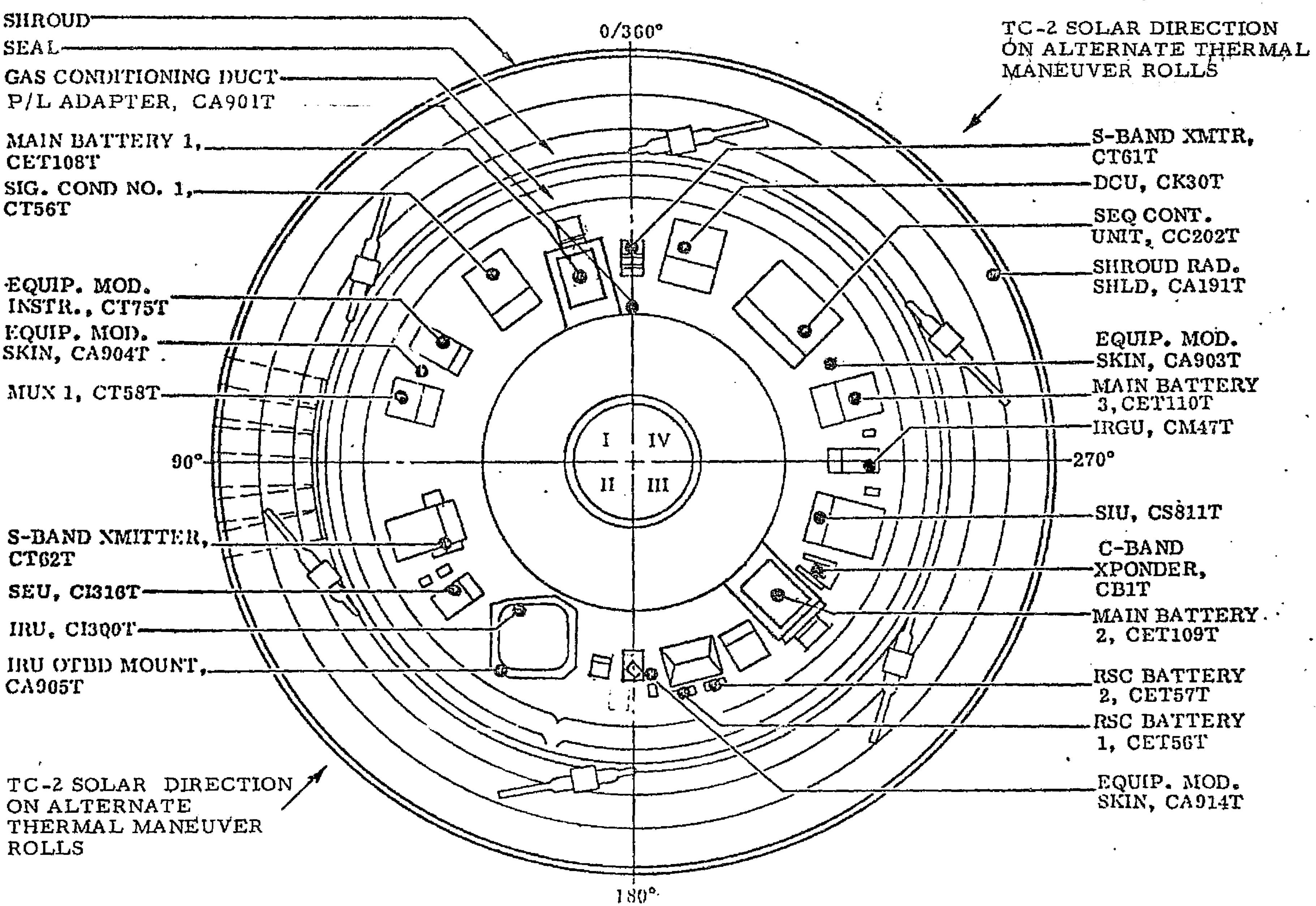


THERMAL AND HEAT TRANSFER

- LO_2 TANK SHIELD INSULATION KIT
  - — THERMAL RESPONSE AND LO_2 TANK FLIGHT HEAT RATES
- INTERMEDIATE BULKHEAD PERFORMANCE FROM PROPELLANT ENERGY BALANCES
- TANK VENT SYSTEMS
  - — THERMAL RESPONSE
- ELECTRONIC EQUIPMENT
  - — THERMAL RESPONSE AND PERFORMANCE
- HYDRAULIC SYSTEM
  - — THERMAL RESPONSE AND PERFORMANCE
- H_2O_2 SYSTEM
  - — THERMAL RESPONSE AND PERFORMANCE
- H_2O_2 SYSTEM EXHAUST IMPINGEMENT HEATING ENVIRONMENT
- MAIN PROPULSION SYSTEM
  - — THERMAL RESPONSE AND PERFORMANCE
- THERMAL CONTROL SUMMARY

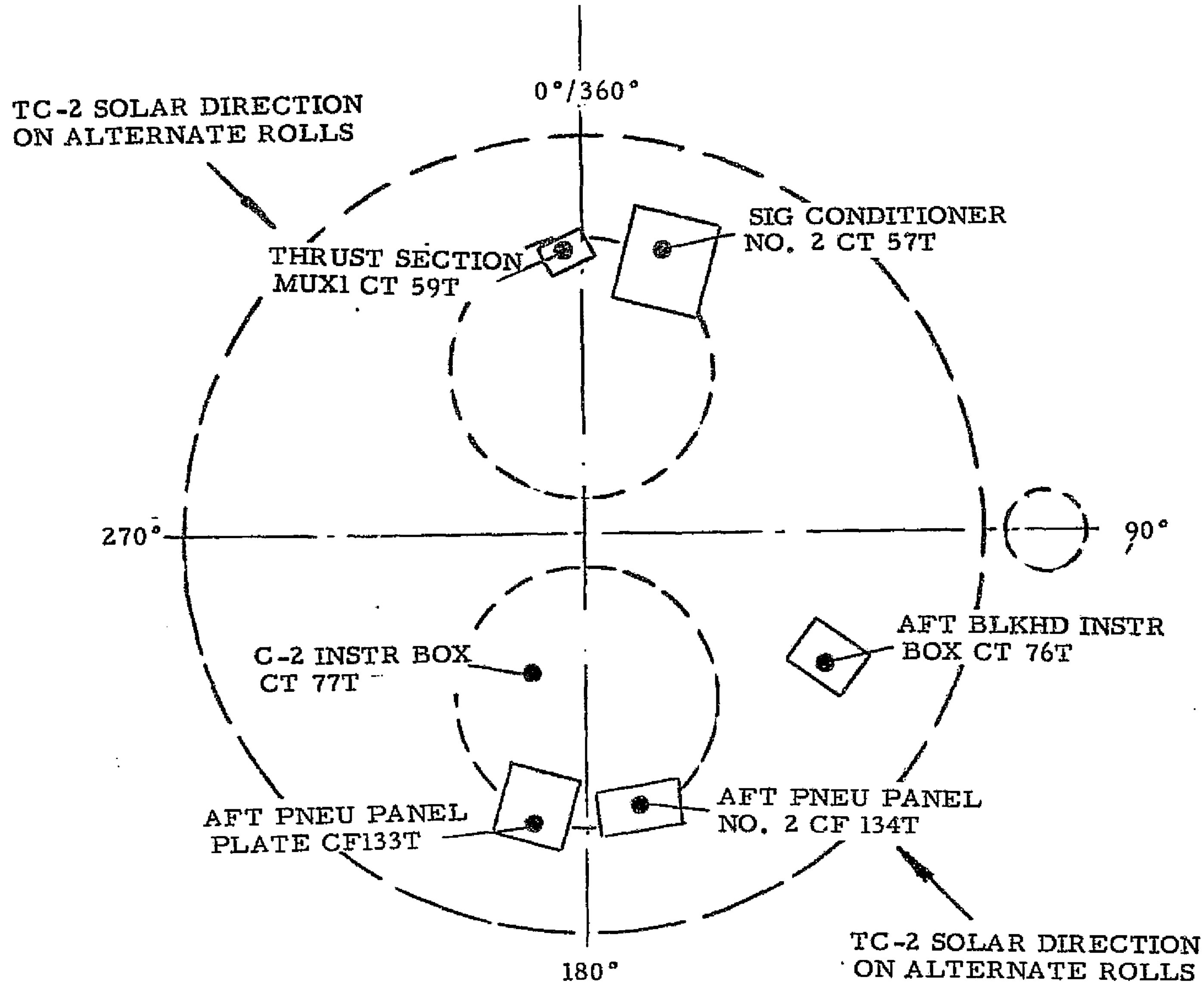
EQUIPMENT MODULE COMPARTMENT TEMPERATURE LOCATIONS

GENERAL DYNAMICS
Convair Aerospace Division



FIGURE

AFT BULKHEAD EQUIPMENT TEMPERATURE LOCATIONS



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COMPONENT TEMPERATURES

MEAS. NO.	DESCRIPTION	TEMPERATURE (°F)					
		LIFTOFF		CSS JETTISON		740 SECONDS*	
		TC-1	TC-2	TC-1	TC-2	TC-1	TC-2
CB1T	C-BAND TRANSPONDER	66	70	65	73	72	75
CC202T	SCU HOUSING WEB	64	72	63	72	63	72
CE56T	RSC BATT 1 INTERNAL	83	108	79	98	77	94
CE57T	RSC BATT 2 INTERNAL	97	57	89	79	86	77
CE108T	MAIN BATT 1 INTERNAL	95	87	96	89	97	90
CE109T	MAIN BATT 2 INTERNAL	81	91	82	91	82	92
CE110T	MAIN BATT 3 INTERNAL	92	78	93	82	95	86
CS811T	SIU SKIN	65	74	65	75	69	77
CI300T	IRU SKIN INTERNAL	80	82	81	84	85	86
CI316T	SEU INTERNAL	65	72	63	73	65	74
CK30T	DCU SKIN	77	87	81	91	87	94
CM47T	IRGU GYRO BLOCK	77	87	77	89	80	93
CT56T	SIG. CONDITIONER NO. 1	62	70	61	70	60	69
CT57T	SIG. CONDITIONER NO. 2	82	81	81	80	81	80
CT58T	EQUIPMENT MODULE MUX 1	63	72	61	70	61	69
CT59T	THRUST SECTION MUX 2	76	71	74	69	75	68
CT61T	S-BAND XMTR INTERNAL - PCM	71	87	79	98	92	108
CT62T	S-BAND XMTR INTERNAL - FM	72	82	75	88	83	94
CT75T	EQUIP MODULE INSTR. BOX	67	73	64	72	64	72
CT76T	AFT BULKHEAD INSTR. BOX	71	75	70	72	69	71
CT77T	C-2 INSTR. BOX	73	69	70	68	69	63

*TIME SELECTED TO ALLOW DIRECT COMPARISON TO TC-1

COMPONENT TEMPERATURES 1-HOUR COAST

MEAS. NO.	DESCRIPTION	TEMPERATURE (°F) START COAST	END COAST
CB1T	C-BAND TRANSPONDER	+80	+81
CC202T	SCU HOUSING WEB	+72	+86
CE56T	RSC BATT 1 INTERNAL	+80	+57
CE57T	RSC BATT 2 INTERNAL	+66	+47
CE108T	MAIN BATT 1 INTERNAL	+96	+108
CE109T	MAIN BATT 2 INTERNAL	+92	+96
CE110T	MAIN BATT 3 INTERNAL	+93	+106
CS811T	SIU SKIN	+84	+101
CI300T	IRU SKIN INTERNAL	+85	+87
CI316T	SEU INTERNAL	+76	+82
CK30T	DCU SKIN	+104	+127
CM47T	IRGU GYRO BLOCK	+100	+115
CT56T	SIG. CONDITIONER NO. 1	+68	+69
CT57T	SIG. CONDITIONER NO. 2	+77	+98
CT58T	EQUIPMENT MODULE MUX 1	+67	+61
CT59T	THRUST SECTION MUX 2	+67	+84
CT61T	S-BAND XMTR INTERNAL - PCM	+124	+148
CT62T	S-BAND XMTR INTERNAL - FM	+103	+114
CT75T	EQUIP MODULE INSTR BOX	+71	+72
CT76T	AFT BULKHEAD INSTR BOX	+70	+75
CT77T	C2 INSTR BOX	+54	+45

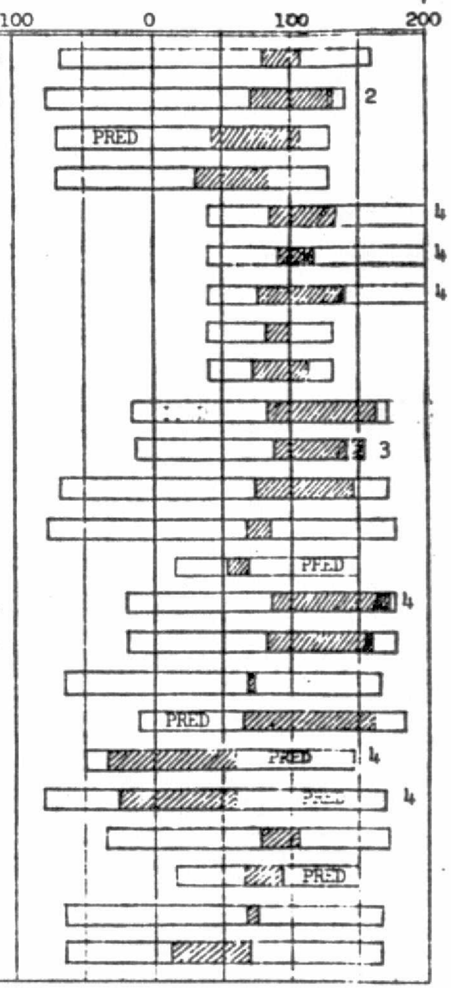
COMPONENT TEMPERATURES – THERMAL ROLL

MEAS. NO.	DESCRIPTION	TEMPERATURE (°F) START 1ST ROLL	START 2ND ROLL	START 3RD ROLL
CB1T	C-BAND TRANSPONDER	85	85	89
CC202T	SCU HOUSING WEB	102	98	110
CE56T	RSC BATT 1 INTERNAL	42	50	44
CE57T	RSC BATT 2 INTERNAL	34	37	30
CE108T	MAIN BATT 1 INTERNAL	113	117	121
CE109T	MAIN BATT 2 INTERNAL	99	101	105
CE110T	MAIN BATT 3 INTERNAL	111	117	121
CS811T	SIU SKIN	114	112	125
CI300T	IRU SKIN INTERNAL	81	87	86
CI316T	SEU INTERNAL	77	90	89
CK30T	DCU SKIN	139	136	147
CM47T	IRGU GYRO BLOCK	131	125	136
CT56T	SIG. CONDITIONER NO. 1	72	68	72
CT57T	SIG. CONDITIONER NO. 2	105	98	99
CT58T	EQUIPMENT MODULE MUX 1	53	59	53
CT59T	THRUST SECTION MUX 2	95	82	86
CT61T	S-BAND XMTR INTERNAL - PCM	166	148	167
CT62T	S-BAND XMTR INTERNAL - FM	109	133	124
CT75T	EQUIP MODULE INSTR BOX	70	68	67
CT76T	AFT BULKHEAD INSTR BOX	70	69	69
CT77T	C2 INSTR BOX	43	40	36

TABLE I

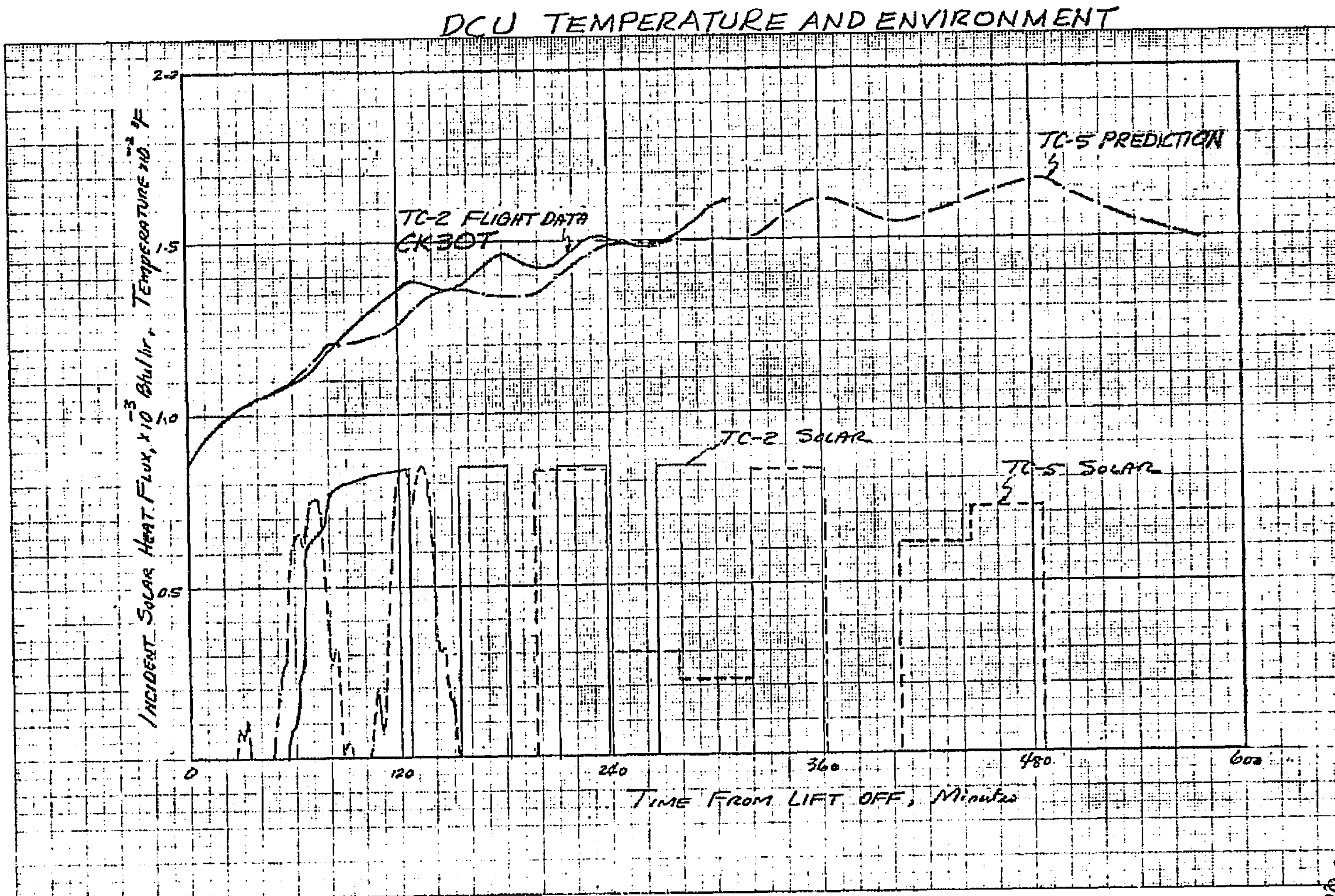
CENTAUR COMPONENT THERMAL CONTROL AS INDICATED BY TC-2 DATA

MEAS. NO.	TC-2 COMPONENT	ANALYSIS DOCUMENT	PRED. RANGE	QUAL RANGE	TC-2 TEMP RANGE[1]
CB1T	C-BAND XPONDER	988-3-70-39	-41 to 111	-65 to 160	69.5 to 108
CC202T	SCU HOUSING WEB	988-3-70-85	-58 to 115	-76 to 140	70 to 132
CET56T	RSC BATTERY 1 INTERNAL	988-3-70-107	-70 to 128	N/A	42 to 107
CET57T	RSC BATTERY 2 INTERNAL	988-3-70-107	-70 to 128	N/A	30 to 84
CET108T	MAIN BATTERY 1 INTERNAL	965-4/HT74/053	56 to 175	40 to 200	86 to 135
CET109T	MAIN BATTERY 2 INTERNAL	965-4/HT74/053	62 to 152	40 to 200	91 to 119
CET110T	MAIN BATTERY 3 INTERNAL	965-4/HT74/053	58 to 175	40 to 200	77 to 140
CI300T	IRU SKIN INTERNAL	HONEYWELL		40 to 130	82 to 100
CI316T	SEU INTERNAL	HONEYWELL		40 to 130	72 to 113
CK30T	DCU SKIN	Teledyne Item 15	-14 to 203	-9 to 170	85 to 162
CM47T	IRGU GYRO BLOCK	966-3/R71/005	- 6 to 139	-12 to 142	88 to 153
CS811T	SIU SKIN	988-3-72-16	-51 to 154	-69 to 172	74 to 147
CT56T	SIGNAL CONDITIONER NO. 1	988-3-70-70	-40 to <172	-76 to 176	68 to 85
CT58T	RMU 1 (EQ. MODULE)	Teledyne Item 15	14 to 150		53 to 71
CT61T	S-BAND XMTR INTERNAL (PCM)	965-4/HT73/017	- 1 to 169	-22 to 176	86 to 172
CT62T	S-BAND XMTR INTERNAL (FM)	988-3-70-14	- 7 to 155	-22 to 176	82 to 159
CT75T	INSTR. BOX (EQ MODULE)	965-4/HT72/053	21 to 130	-65 to 165	66 to 73
CA905T	IRU OUTBOARD MOUNT	988-3-71-19	-12 to 182	N/A	64 to 161
CF133T	AFT PNEU. PANEL PLATE	988-3-71-02	-50 to 147	N/A	-36 to 60
CF134T	AFT PNEU PANEL NO. 2	965-4/HT74/014	-80 to 170	N/A	-26 to 60
CT57T	SIGNAL CONDITIONER NO. 2	988-3-70-70	-32 to 172	-76 to 176	77 to 105
CT59T	RMU 2 (THRUST SECTION)	Teledyne Item 15	14 to 150		64 to 95
CT76T	INSTR BOX (AFT BULKHEAD)	965-4/HT72/053	21 to 130	-65 to 165	65 to 75
CT77T	C-2 ENGINE INSTR BOX	988-3-70-73	-15 to 95	-65 to 165	11 to 69



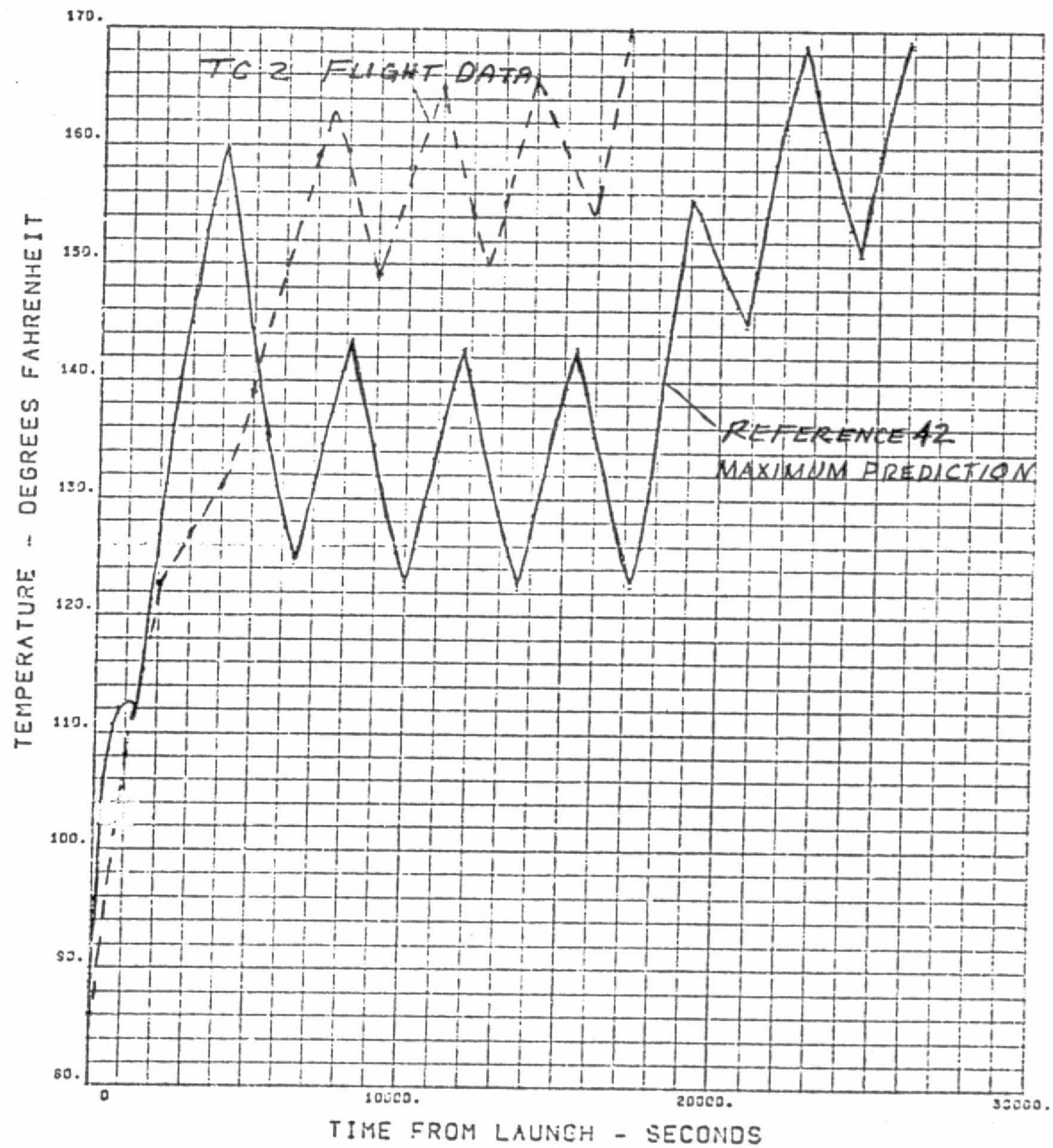
SCU - SEQUENCE CONTROL UNIT
RSC - RANGE SAFETY CONTROL
IRU - INERTAIL REFERENCE UNIT
SEU - SYSTEMS ELECTRONICS UNIT
DCU - DIGITAL COMPUTER UNIT
IRGU - INSTRUMENTATION RATE GYRO UNIT
SIU - SERVO INVERTER UNIT
RMU - REMOTE MULTIPLEXER

1. UNSHADED AREA REPRESENTS QUALIFICATION RANGE, EXCEPT WHERE NOTED. SHADED AREA IS TC-2 MEASURED RANGE.
2. SCU PREDICTED TEMP IS SKIN TEMP.
3. OUT-OF-BAND TEMP RESPONSE IS IN STUDY
4. PREDICTED & QUAL TEMPS ASSUME THERMAL MANEUVER CONDITIONS.

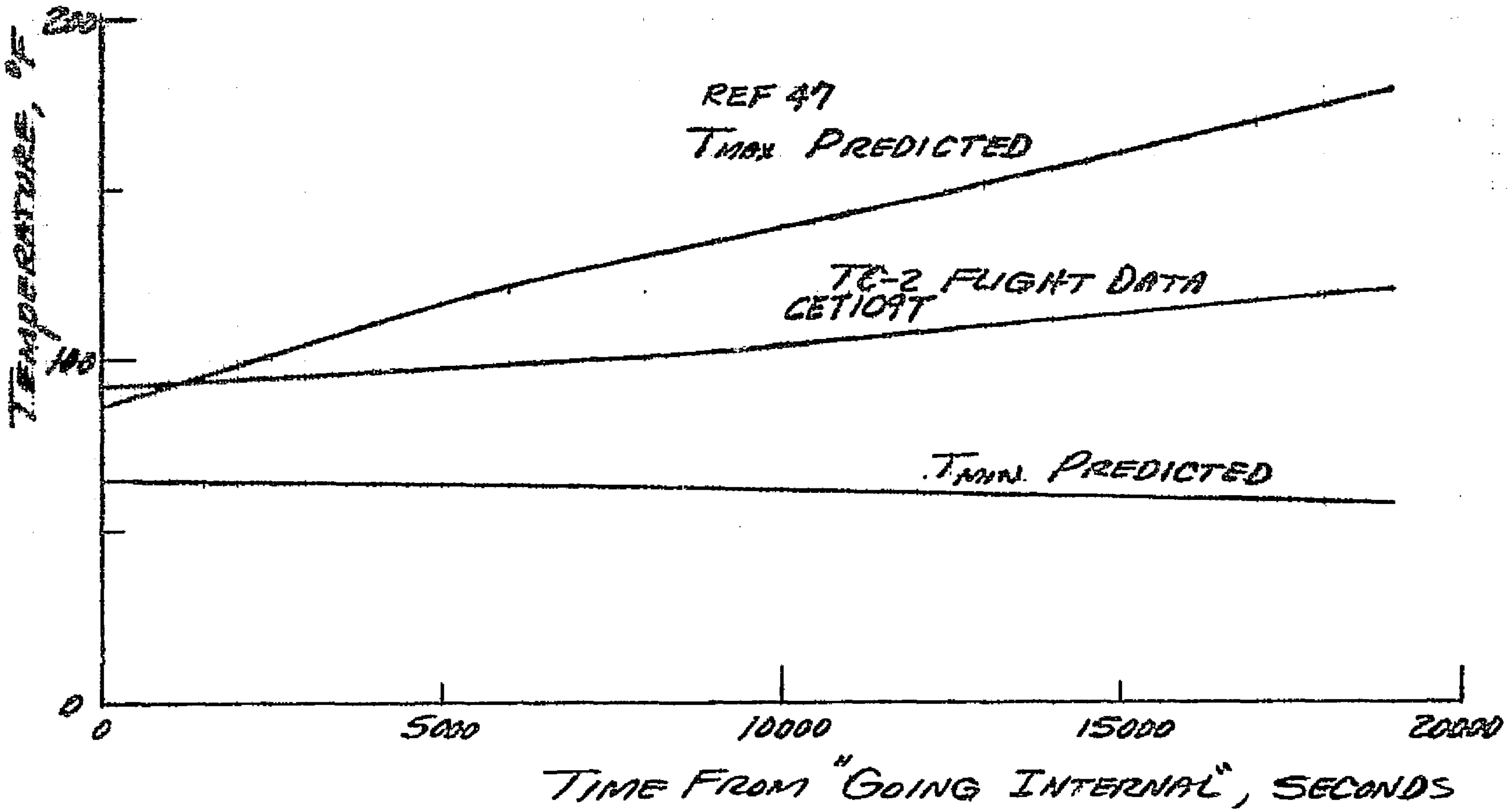


DCU TEMPERATURE AND ENVIRONMENT
TC-5 PREDICTION
TC-2 FLIGHT DATA
CK30T
TC-2 SOLAR
TC-5 SOLAR
INCIDENT SOLAR HEAT FLUX, x10^-3 Btu/hr, TEMPERATURE x10^-2 °F
2.0
1.5
1.0
0.5
0
120
240
360
480
600
TIME FROM LIFT OFF, Minutes

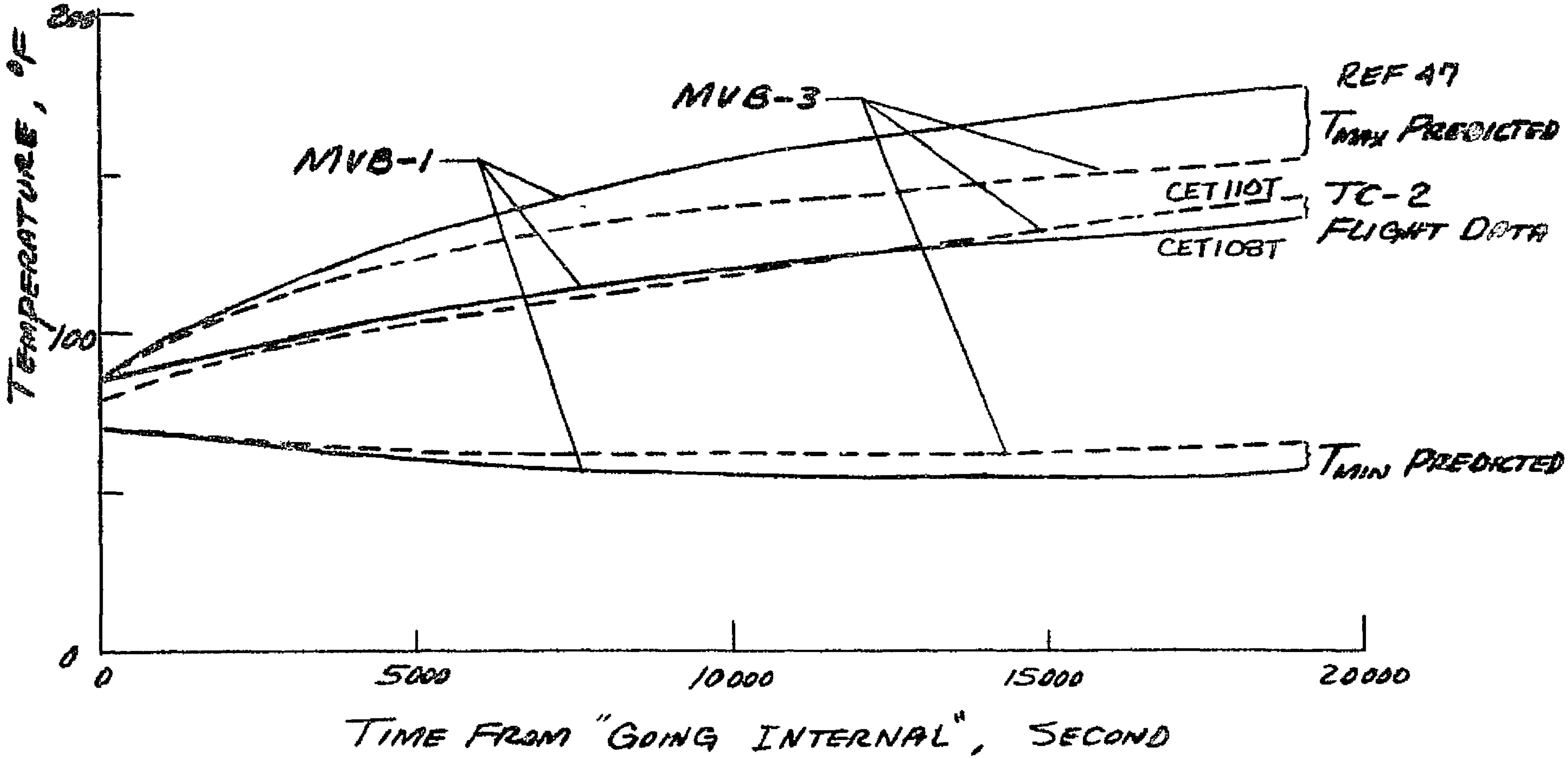
FIGURE 9-4. S-BAND TRANSMITTER MOUNTING SURFACE MAX. TEMP. CASE WITH DIODE PACKAGE RADIATOR



TEMPERATURE HISTORY FOR MVB-2 HAVING A WHITE POLYURETHANE PAINT STRIPE AROUND BATTERY CASE



TEMPERATURE HISTORY FOR MVB-1 & -3 HAVING A WHITE POLYURETHANE PAINT EXTERIOR SURFACE



THERMAL AND HEAT TRANSFER

- LO_2 TANK SHIELD INSULATION KIT
  - THERMAL RESPONSE AND LO_2 TANK FLIGHT HEAT RATES
- INTERMEDIATE BULKHEAD PERFORMANCE FROM PROPELLANT ENERGY BALANCES
- TANK VENT SYSTEMS
  - THERMAL RESPONSE
- ELECTRONIC EQUIPMENT
  - THERMAL RESPONSE AND PERFORMANCE
- HYDRAULIC SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE
- H_2O_2 SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE
- H_2O_2 SYSTEM EXHAUST IMPINGEMENT HEATING ENVIRONMENT
- MAIN PROPULSION SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE
- THERMAL CONTROL SUMMARY

TABLE 10-1. HYDRAULIC SYSTEM FLIGHT TEMPERATURES.

MEAS. NO.	COMPONENT	FLIGHT TEMPERATURE, °F LIFT-OFF 0 SEC	SHROUD JETT. 319 S	MES1 483 S	MECO1 +166 750 S	MES1 1900 S	MECO2 2173 S	MES1 5773 S	MECO3 5784 S	MES4 16554 S	MECO4 +368 17006 S	END 18242 S	PREDICTED TEMP. AT MES -4 MAX	MIN.
CH2T	C-1 HYD PWR PACK*	56	56	56	80	79	138	120	120	73	88	80	75	57
CH5T	C-1 HYD MANIFOLD	64	60	60	88	71	168	92	115	100	102**	48		35
CH9T	C-1 RECIRC MTR HSG	56	50	56	58	72	74	115	120	70	82	100	74	56
CH33T	C-1 YAW ACCU BODY*	80	76	75	92	85	141	114	114	70	80	66		
CH4T	C-2 HYD PWR PACK*	58	58	58	78	78	132	108	108	58	69	59	66	
CH6T	C-2 HYD MANIFOLD	48	47	46	104	68	158	105	114	12	60**	18		10†
CH10T	C-2 RECIRC MTR HSG	60	52	52	80	95	88	88	100	64	80	60	65	43
CH36T	C-2 PITCH ACCU BODY*	72	69	70	90	84	140	115	115	64	68	58		
INDICATED MOUNT TEMPERATURES														
CP63T	C-1 THST CHM JACKET	50	43	43	-256	-100	-256	-15	-60	20	-150	-215		
CP745T	C-1 ENG BELL S5000 TB	60	52	60	-325	50	-310	245	-40	230	-125	150		
CP124T	C-1 ENG LOX PUMP	-74	-90	-80	-275	-145	-275	-142	-280	-75	-275	-230		
CP98T	C-2 THST CHM JACKET	45	40	40	-265	-82	-265	-55	-160	-20	-160	-200		
CP746T	C-2 ENG BELL S5000 TB	62	55	60	-320	-40	-300	0	-245	160	-160	-120		
CP125T	C-2 ENG LOX PUMP	-55	-80	-82	-260	-100	-260	-150	-260	-74	-265	-205		

*SHIELDED

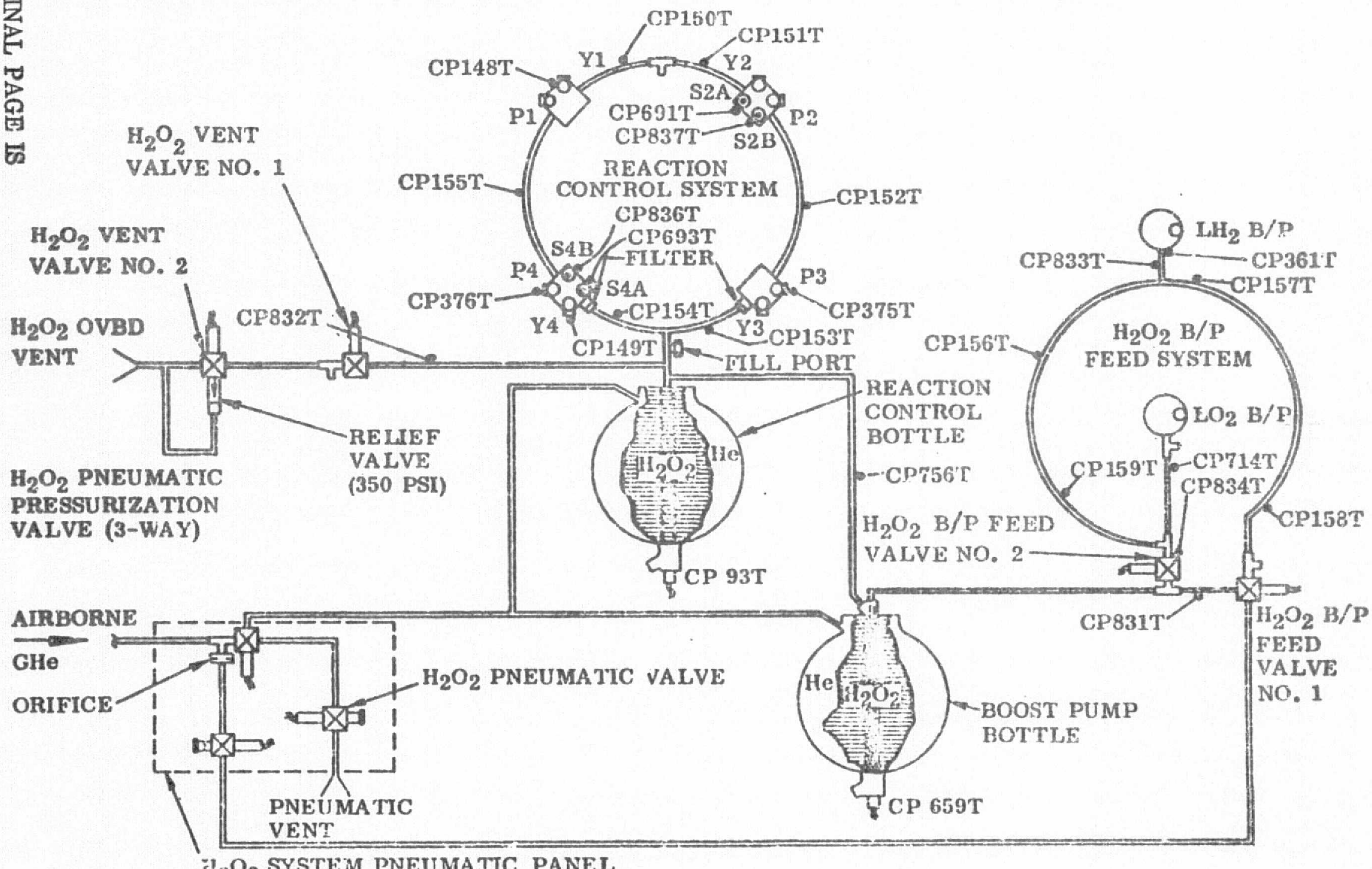
**MECO4 TEMPERATURES

†ASSUMED MINIMUM WITH RECIRCULATION SYSTEM HEAT DEMAND. MINIMUM PREDICTION WOULD TURN RECIRC SYSTEM ON AT MECO -3 +5800 SEC (ACTUAL OCCURRED AT MECO3 +9626 SEC).

THERMAL AND HEAT TRANSFER

- LO_2 TANK SHIELD INSULATION KIT
  - THERMAL RESPONSE AND LO_2 TANK FLIGHT HEAT RATES
- INTERMEDIATE BULKHEAD PERFORMANCE FROM PROPELLANT ENERGY BALANCES
- TANK VENT SYSTEMS
  - THERMAL RESPONSE
- ELECTRONIC EQUIPMENT
  - THERMAL RESPONSE AND PERFORMANCE
- HYDRAULIC SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE
- H_2O_2 SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE
- H_2O_2 SYSTEM EXHAUST IMPINGEMENT HEATING ENVIRONMENT
- MAIN PROPULSION SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE
- THERMAL CONTROL SUMMARY

H_2O_2 AND REACTION CONTROL SYSTEMS



FORM 73-1 (REV. 6-61)

Table 11-I

H_2O_2 SYSTEM FLIGHT TEMPERATURE LEVELS

(^oF @ Time of Flight)

EVENT ⟶

Meas	Description	LO-3 Min	Lift-off	Max w/ Reduced Heat Removal	Min Due to Vent Cooling	Start of Flow or Impinge	MECO1	1st Coast Min	1st Coast Max	Settle-2 or BPS-2	MECO2 or Peak	2nd Coast Max	2nd Coast Min	Settle-3 or BPS-3	MECO3 or Peak	3rd Coast Max	3rd Coast Min	Settle-4 or BPS-4	Terminal Operation Max	Terminal Operation Min
				← ^oF @ Seconds		→		^oF @ Minutes		**	**	^oF @ Minutes		**	**	^oF @ Minutes		**	^oF @ Minutes	
CP 93T	Att Control H_2O_2 Bottle	87	85*	-	-	85@437	86	86@10	89@20	88^B	89^M	91@96	88@[illegible]0	91^B	91^M	93@1[illegible]0	85@275	85^B	88@280	84@295
CP659T	B/P H_2O_2 Bottle	82 ↑ 90	81*	-	-	82@437	84	84@10	87@30	87^B	88^M	92@92	87@45	92^B	91^M	91@96	85@275	85^B	88@282	84@306
CP756T	H_2O_2 Crossover Line	79 ↑ 95	87	88@20	85@55	93@437	95	93@11	95@10	93^B	94^M	99@62	92@51	95^S	95^M	95@100	90@260	92^B	129@114	88@305
CP150T	QD 1 A/C Line	71 ↑ 73	72	73@20	65@[illegible]0	72@319	88	-	93	93^B	85^M	120@63	85@36	87^S	121^P	108@[illegible]	63@186	72^S	95	83@316
CP151T	QD 2 A/C Line	77	75	77@25	74@60	80@319	90	-	95	95^S	109^M	133@49	103@39	104^S	115^P	160@145	85@124	146^S	96@282	85@312
CP152T	QD 2/3 A/C Line	62 ↑ 76	72	73@25	68@70	70@319	90	89@20	91@11	89^S	94^M	99@54	64@96	64^S	90^P	108@143	63@124	88^S	87	70@307
CP153T	QD 3 A/C Line	79 ↑ 89	81	82@20	77@80	88@319	98	95	-	95^S	95^M	112@88	95@50	111^S	95^M	107@109	85@143	93^S	90@298	117@316
CP154T	QD 4 A/C Line	84 ↑ 91	86	-	80@100	87@319	100	96	-	96^S	102^M	123@88	96@38	117^S	96^M	130@124	96	99^S	92@298	135@314
CP155T	QD 1/4 A/C Line	65 ↑ 73	70	71@30	68@80	72@319	95	95	95	95^S	95^M	134@89	93@50	134^S	96^M	137@124	87@262	100^S	94	119@314
CP831T	LN Btwn BF FD Valves	78 ↑ 84	82	84@20	81@60	101@437	92	92@10	127@31	127^B	93^M	>150@96	93@36	$>150^M$	93^M	147@180	93@96	140^B	141@316	90@282
CP157T	QD 2 LH_2 B/P H_2O_2 Line		69	69@15	42@100	66@319	92	85@26	107@31	107^B	94^M	156@56	70@96	70^B	94^P	175@153	65@125	108^B	92@282	74@316
CP158T	QD 3 LH_2 B/P H_2O_2 Line		68	68.5@15	57@80	66@437	89	87@31	90@18	87^B	90^M	101@65	86@54	89^B	85^M	101@191	89@125	90^B	91@316	46@285
CP159T	QD 4 LH_2 B/P H_2O_2 Line		70	72@15	63@70	75@437	92	92@10	190@31	190^B	96^M	190@96	96@36	190^B	107^M	192@126	110@153	181^B	200@291	99@277
CP833T	LH_2 B/P Inlet Line		84	-	67@150	70@437	97	97@31	127@14	97^B	150^M	172@67	108@96	108^B	97^M	121@180	75@127	115^B	96@285	81@316
CP361T	LH_2 B/P Sup Ln Nr Orf		77	-	52@80	65@437	135	104@30	152@12	104^B	175^M	250@53	134@96	134^B	114^M	143@107	83@245	102^B	143@293	100@315
CP714T	LO_2 B/P Inlet Line		66	-	23@100	76@437	105	98@11	117@17	110^B	108^M	161@96	107@37	161^B	105^M	148@114	75@264	108^B	132@299	99@284
CP156T	QD 1 LH_2 B/P H_2O_2 Fitting		73	-	69@80	69@437	88	85@31	89@11	85^B	105^P	122@58	94@42	105^B	109^P	109@96	54@220	60^B	91@282	69@307
CP832T	H_2O_2 Vent Line No. 1	83	87		87	88@437	87	87@10	89@31	89^B	88^M	93@96	87@70	93^B	91^M	107@132	81@275	81^B	111@316	72@276
CP834T	B/P Fd Valve 2 Body		78	-	76@40	78@437	90	90@10	94@20	92^B	96^M	109@95	96@36	106^M	100^M	104@105	77@275	77^B	89@283	86@280
CP710T	LH_2 B/P Orifice Holder		77	-	73@50	71@437	95	94@31	103@15	94^B	104^M	182@72	104@36	167^B	107^M	120@155	96@125	97^B	101@287	94@277
CP711T	LO_2 B/P Orifice Holder		65	-	63@50	63@437	94	94@10	113@17	107^B	101^M	168@96	101@36	168^B	118^M	155@140	113@276	113^B	140@316	98@277

*Flow data indicates H_2O_2 temperature is 95°F in A/C bottle and 90°F in B/P bottle.

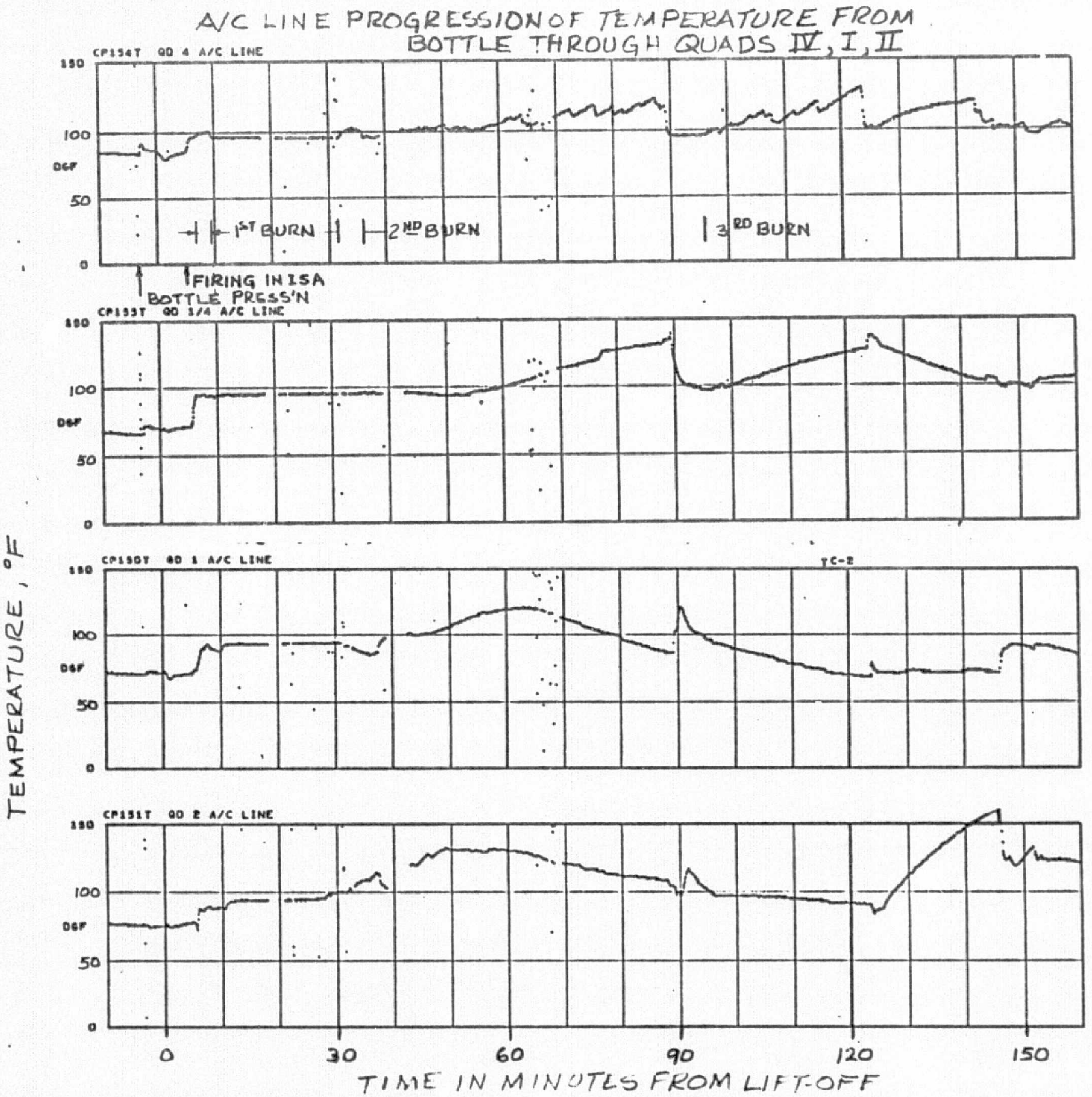
**Superscripts:

- B indicates at boost pump start
- S indicates at engine start preparatory settling
- M indicates at MECO
- P indicates peak due to firing higher than at MECO

TABLE 11-III. SUMMARY OF H_2O_2 COMPONENT TEMPERATURE RANGE BY CATEGORY (^oF).

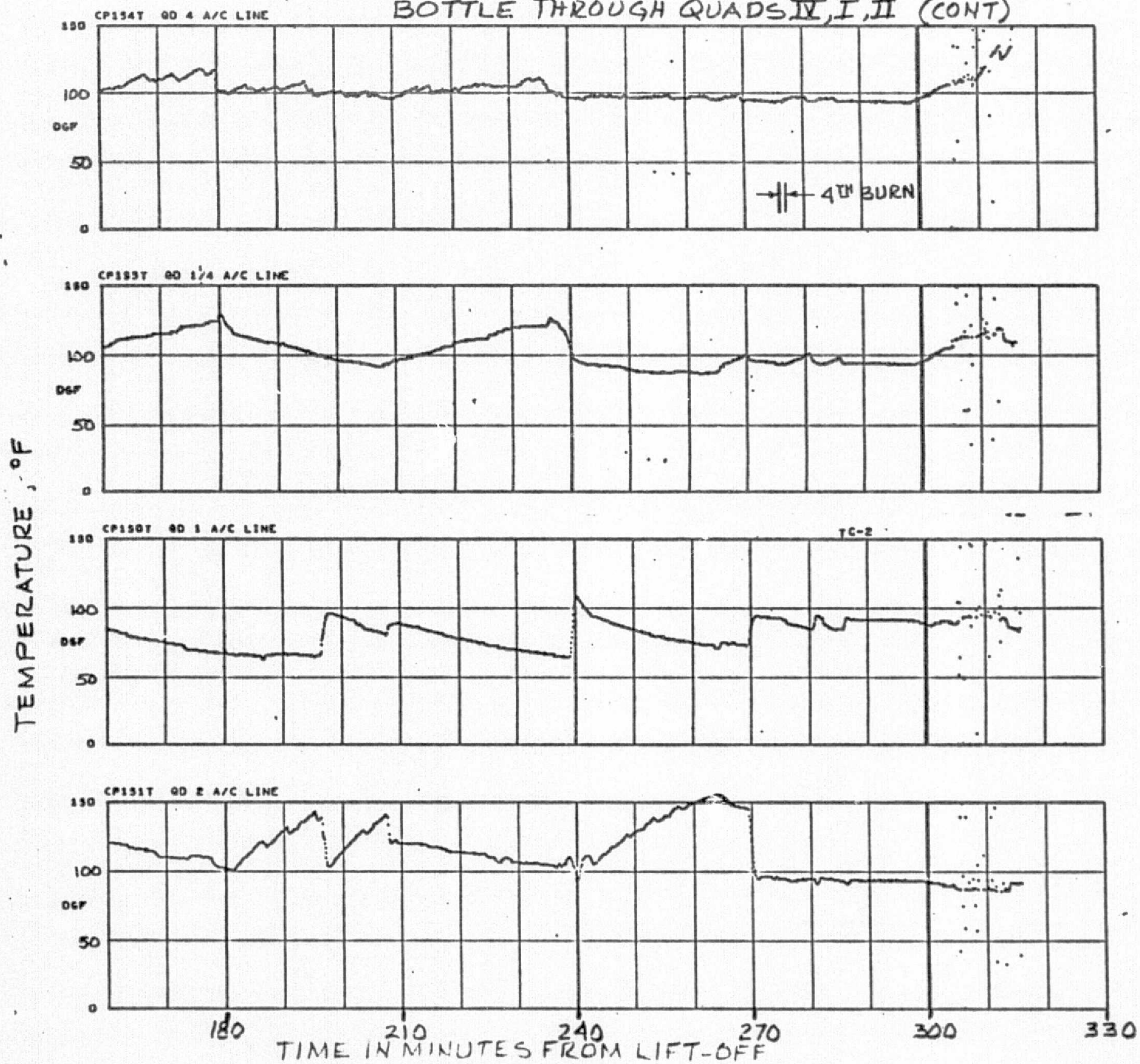
	LIFTOFF		ΔT VENT COOLING		AT 1ST FLOW		1ST COAST		2ND COAST		3RD COAST	
	MAX	MIN.	MAX	MIN.	MAX	MIN.	MAX	MIN.	MAX	MIN.	MAX	MIN.
BOTTLES (CP93, 659T)	95	90	0	0	85	82	89	84	92	87	93	85
HEATED FULL LINES (CP150, 151, 152, 153, 154, 155, 756, 831T)	87	70	-8	-3	101	70	127	89	160*	64	160	63
HEATED EMPTY LINES (CP157, 158, 159T)	70	68	-27	-4	75	66	190	87	190	70	192	65
UNHEATED EMPTY LINES (CP361, 714, 833T)	84	66	-43	-17	76	65	152	97	250	107	148	75
SHIELDED LINE (CP156, 832T)	87	73	-17†	0	88	69	89	85	122	87	107	54
VALVES, ORIFICE BLOCKS (CP710, 711, 834T)	78	65	-4	-2	78	63	113	90	182	96	155	77
ENGINE CHAMBERS (CP148, 149, 375, 376, 691, 693, 836, 837T)	78	65	-28	-4	80	60						

*CP831T OSH @ 150° F ESTIMATE 160° F PEAK.
†INCLUDES CP833T RESPONSE DURING VENTING.

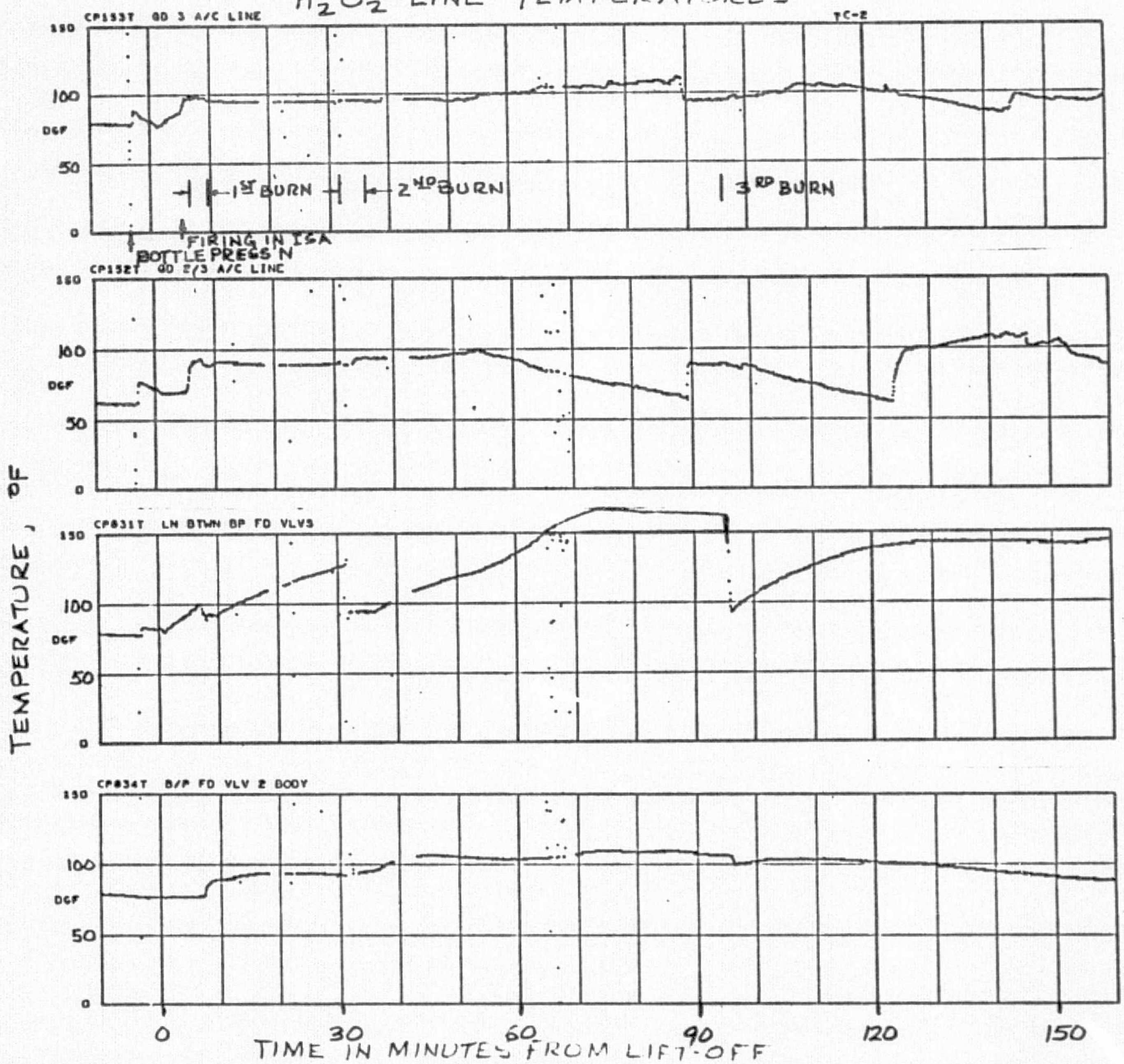


A/C LINE PROGRESSION OF TEMPERATURE FROM BOTTLE THROUGH QUADS IV, I, II
CP154T QD 4 A/C LINE
CP153T QD 3/4 A/C LINE
CP150T QD 1 A/C LINE
CP151T QD 2 A/C LINE
TC-2
1ST BURN
2ND BURN
3RD BURN
FIRING IN ISA
BOTTLE PRESS'N
150
100
50
0
DEF
TEMPERATURE, °F
0
30
60
90
120
150
TIME IN MINUTES FROM LIFT-OFF

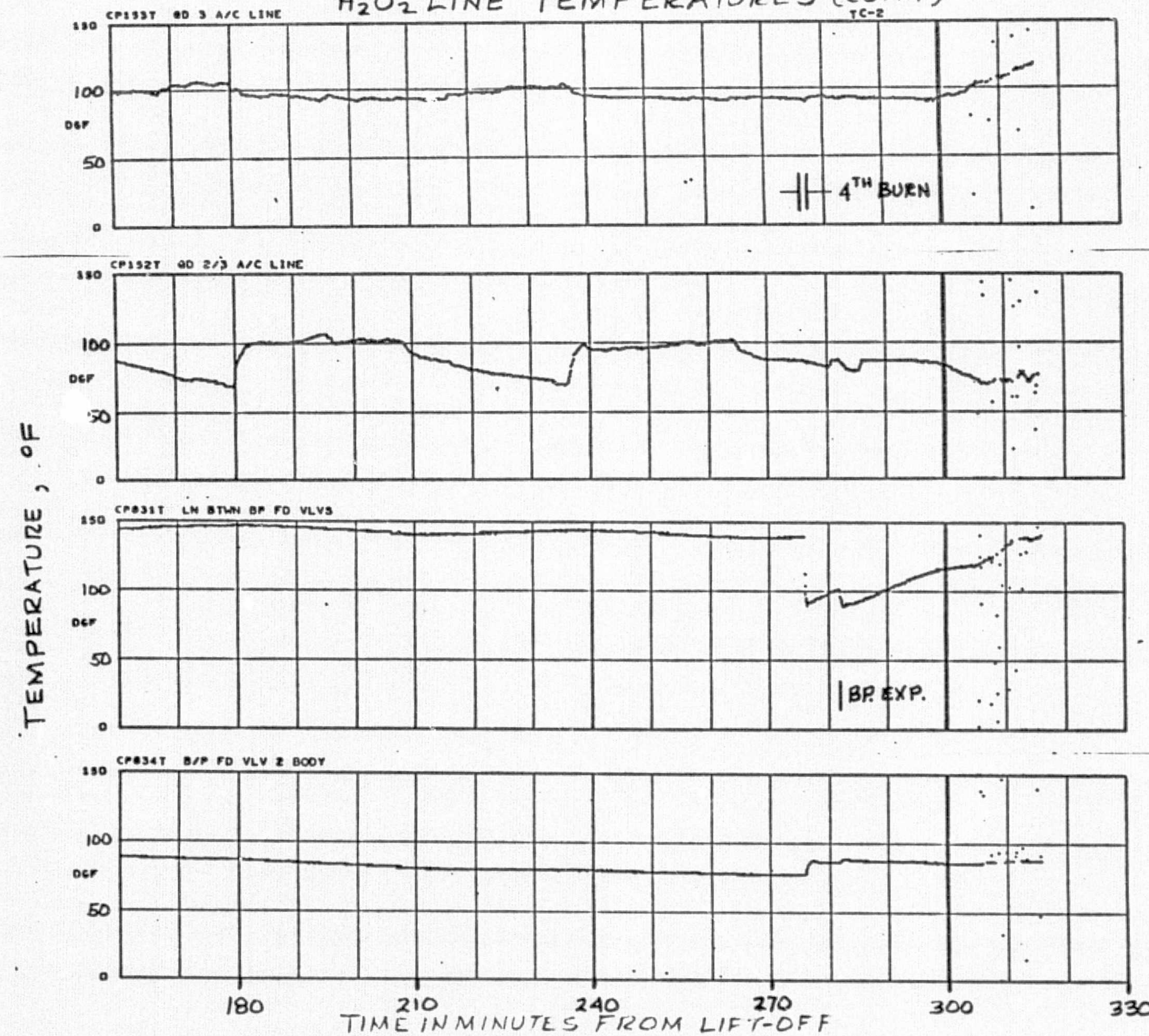
A/C LINE PROGRESSION OF TEMPERATURE FROM BOTTLE THROUGH QUADS IV, I, II (CONT)

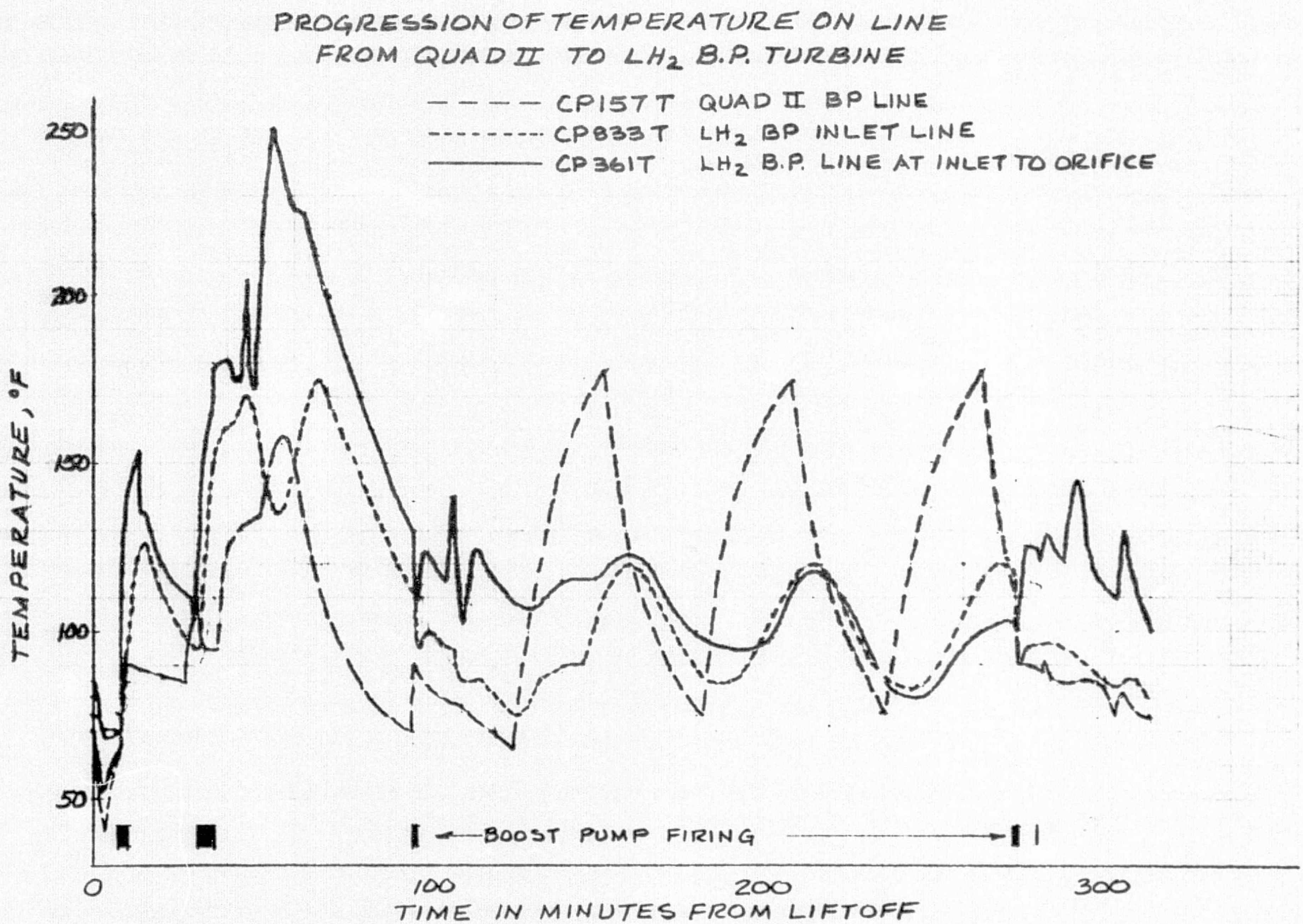


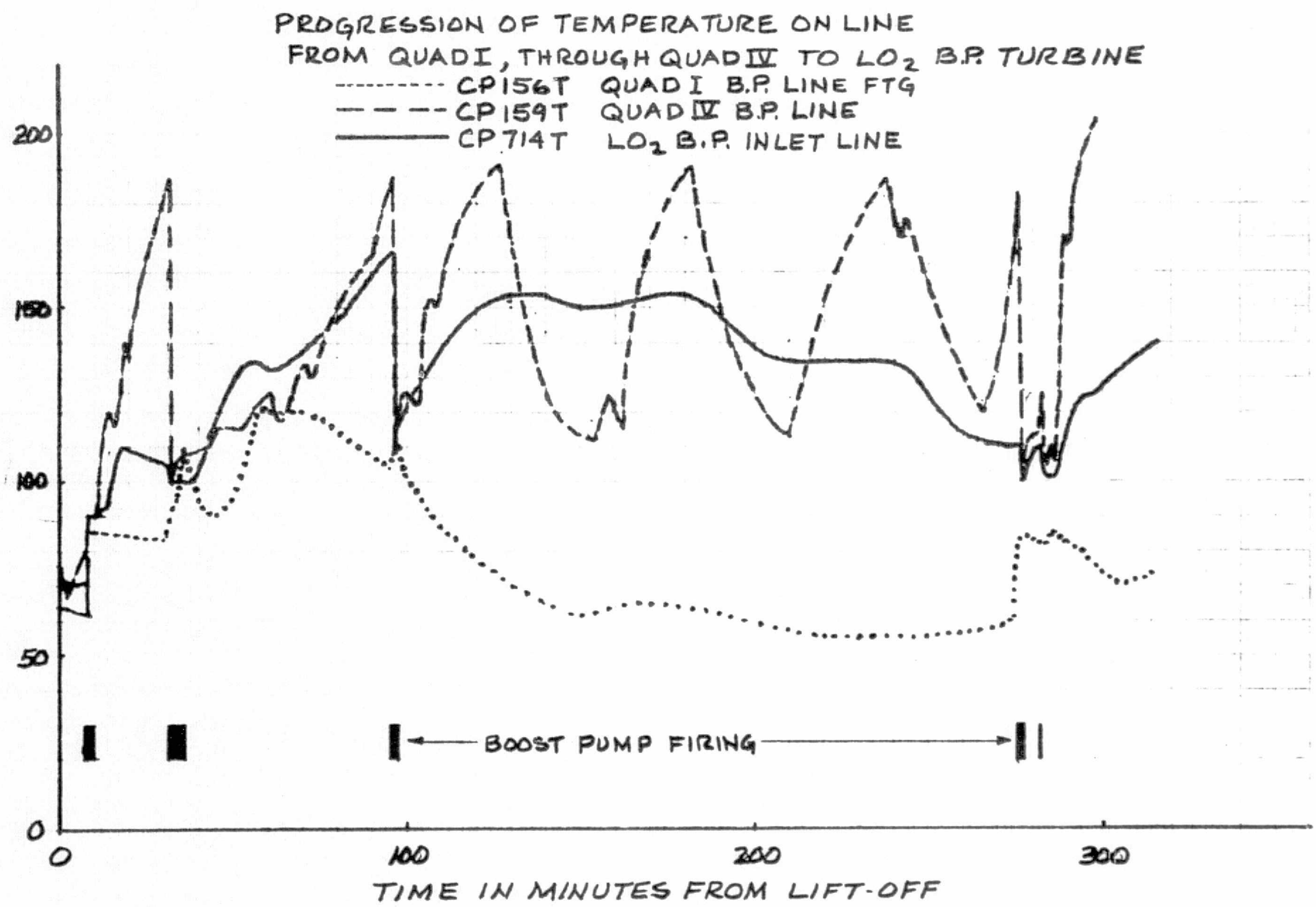
H_2O_2 LINE TEMPERATURES

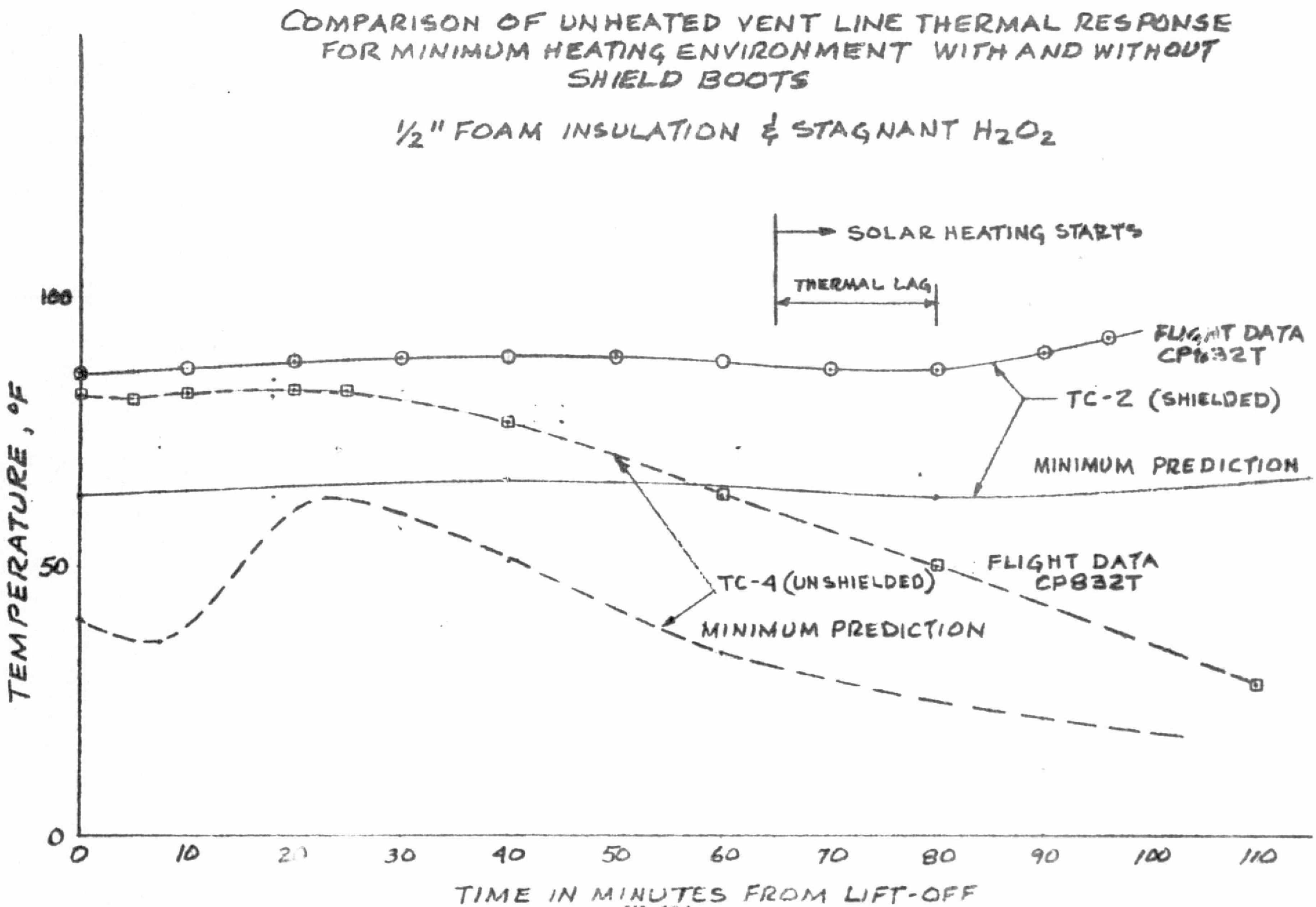


H_2O_2 LINE TEMPERATURES (CONT)



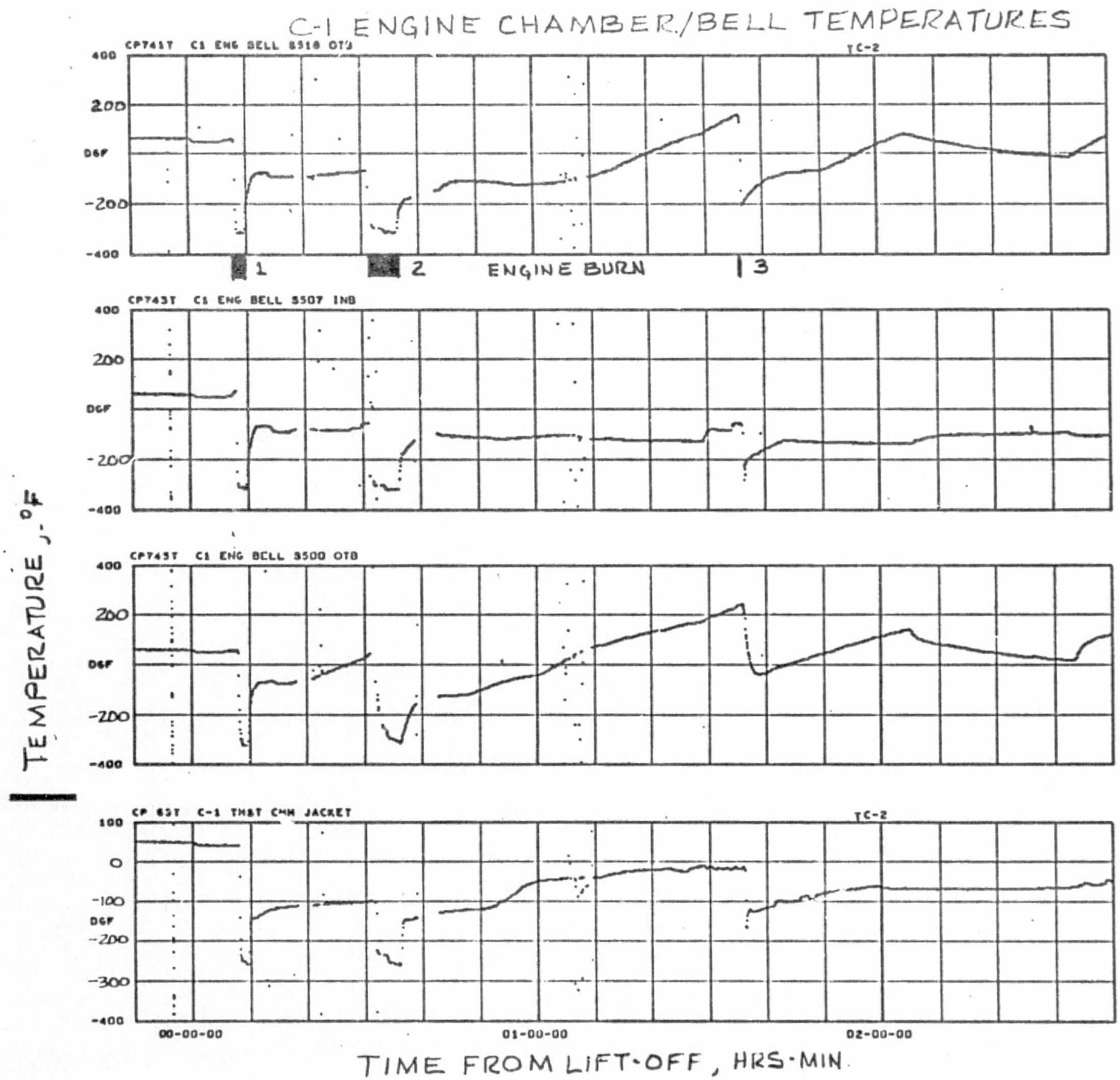

PROGRESSION OF TEMPERATURE ON LINE
FROM QUAD II TO LH2 B.P. TURBINE
CP157T QUAD II BP LINE
CP833T LH2 BP INLET LINE
CP361T LH2 B.P. LINE AT INLET TO ORIFICE
250
200
150
100
50
TEMPERATURE, °F
BOOST PUMP FIRING
0
100
200
300
TIME IN MINUTES FROM LIFTOFF


PROGRESSION OF TEMPERATURE ON LINE
FROM QUAD I, THROUGH QUAD IV TO LO2 B.P. TURBINE
CP156T QUAD I B.P. LINE FTG
CP159T QUAD IV B.P. LINE
CP714T LO2 B.P. INLET LINE
200
150
100
50
0
BOOST PUMP FIRING
0
100
200
300
TIME IN MINUTES FROM LIFT-OFF


COMPARISON OF UNHEATED VENT LINE THERMAL RESPONSE
FOR MINIMUM HEATING ENVIRONMENT WITH AND WITHOUT
SHIELD BOOTS
1/2" FOAM INSULATION & STAGNANT H_2O_2
SOLAR HEATING STARTS
THERMAL LAG
FLIGHT DATA
CP832T
TC-2 (SHIELDED)
MINIMUM PREDICTION
FLIGHT DATA
CP832T
TC-4 (UNSHIELDED)
MINIMUM PREDICTION
TEMPERATURE, °F
0
50
100
0
10
20
30
40
50
60
70
80
90
100
110
TIME IN MINUTES FROM LIFT-OFF

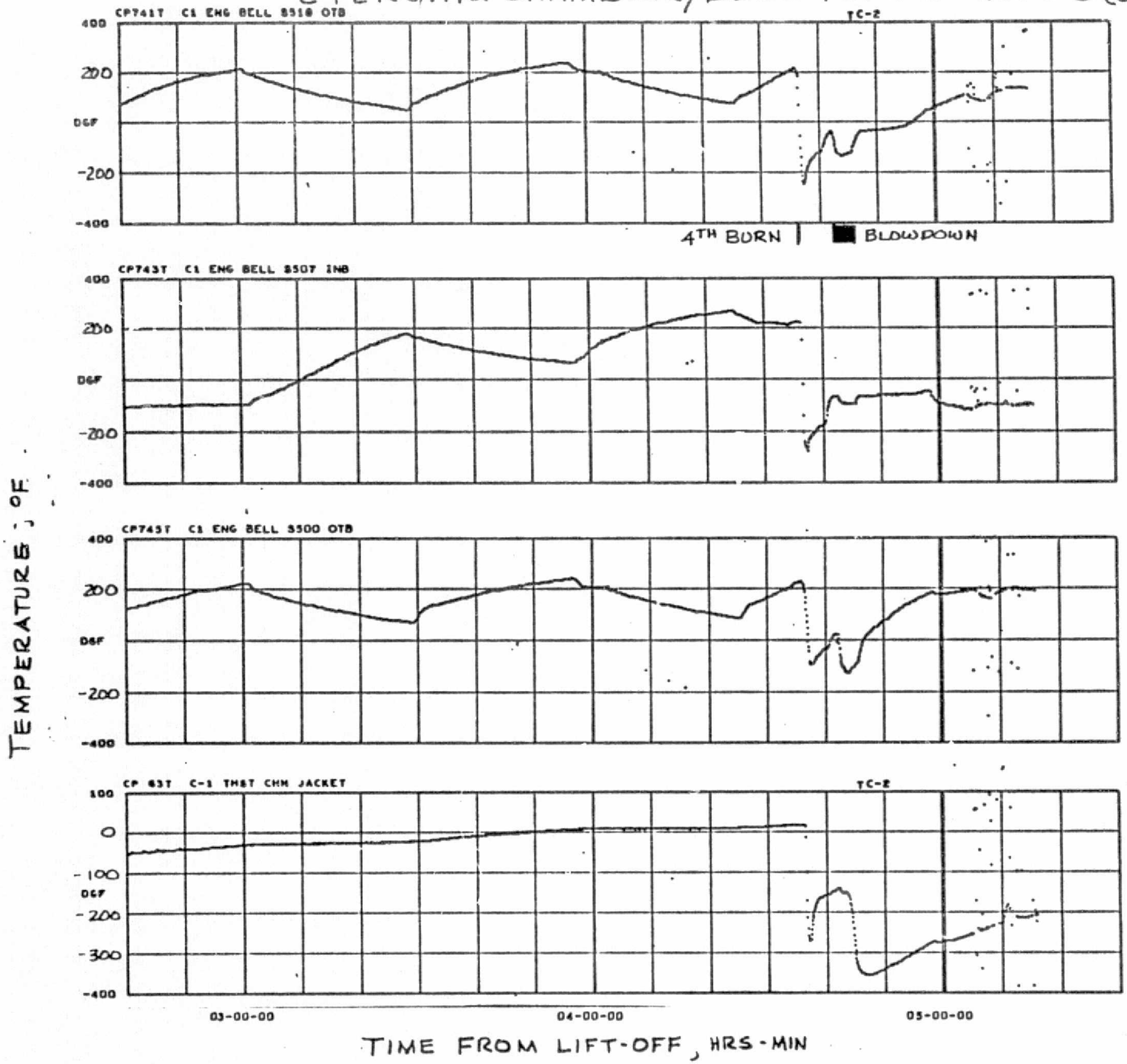
THERMAL AND HEAT TRANSFER

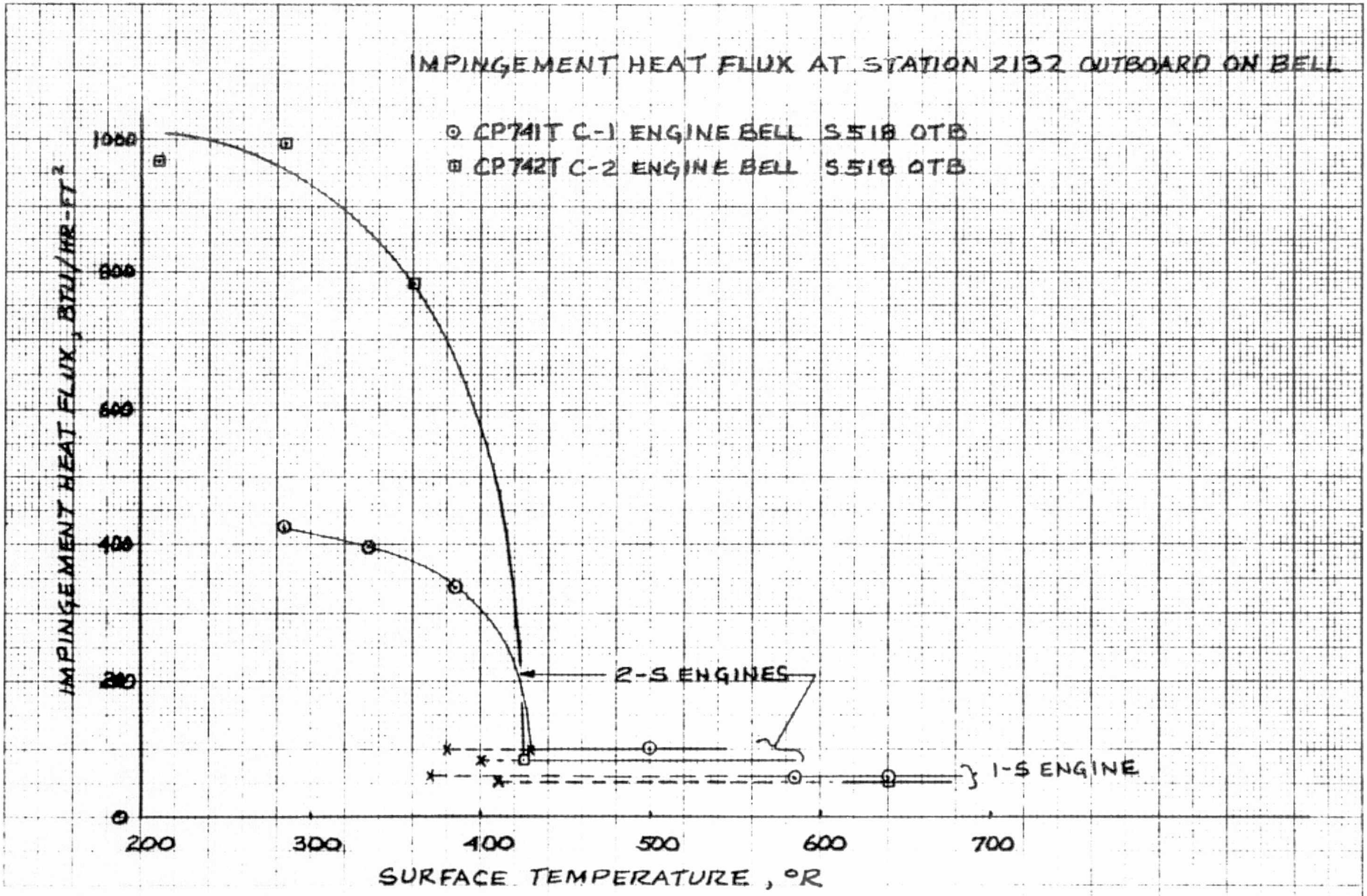
- LO_2 TANK SHIELD INSULATION KIT
  - THERMAL RESPONSE AND LO_2 TANK FLIGHT HEAT RATES
- INTERMEDIATE BULKHEAD PERFORMANCE FROM PROPELLANT ENERGY BALANCES
- TANK VENT SYSTEMS
  - THERMAL RESPONSE
- ELECTRONIC EQUIPMENT
  - THERMAL RESPONSE AND PERFORMANCE
- HYDRAULIC SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE
- H_2O_2 SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE
- H_2O_2 SYSTEM EXHAUST IMPINGEMENT HEATING ENVIRONMENT
- MAIN PROPULSION SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE
- THERMAL CONTROL SUMMARY



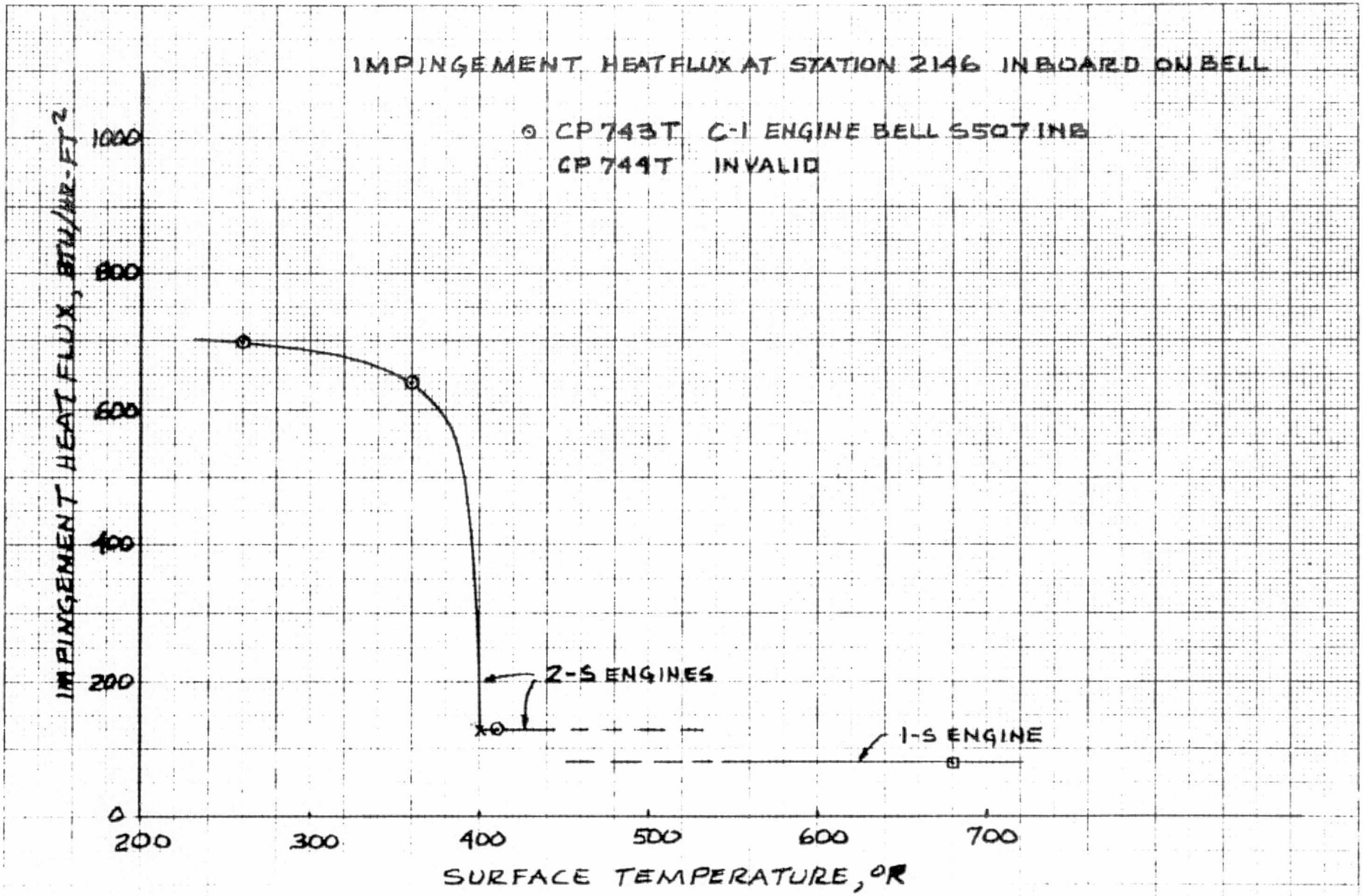
C-1 ENGINE CHAMBER/BELL TEMPERATURES
CP741T C1 ENG BELL 3518 OTB
TC-2
ENGINE BURN
1
2
3
CP743T C1 ENG BELL 3507 INB
CP745T C1 ENG BELL 3500 OTB
CP 63T C-1 THST CHM JACKET
TC-2
400
200
DGF
-200
-400
100
0
-100
-300
TEMPERATURE, °F
00-00-00
01-00-00
02-00-00
TIME FROM LIFT-OFF, HRS-MIN

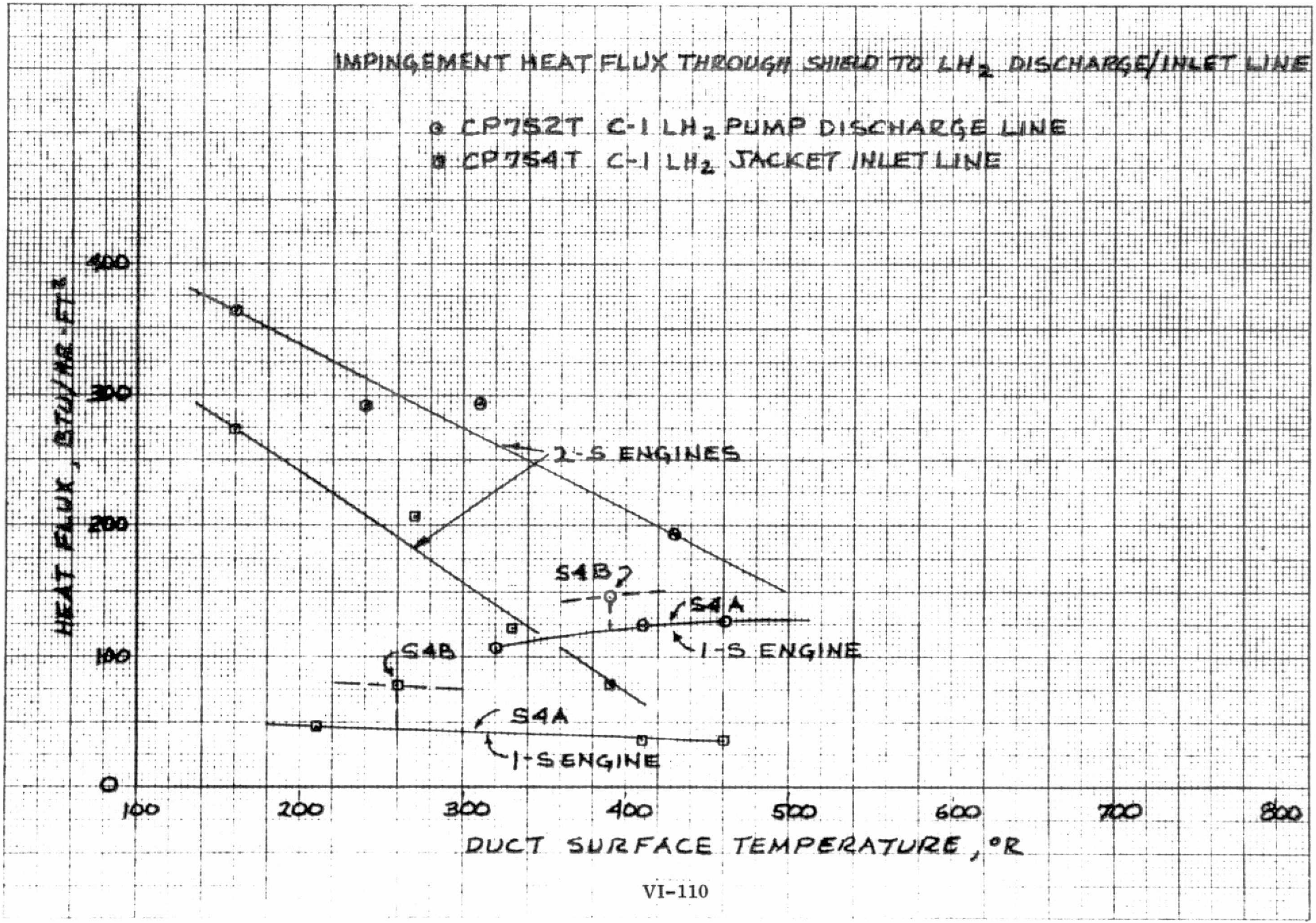
C-1 ENGINE CHAMBER/BELL TEMPERATURES (CONT)

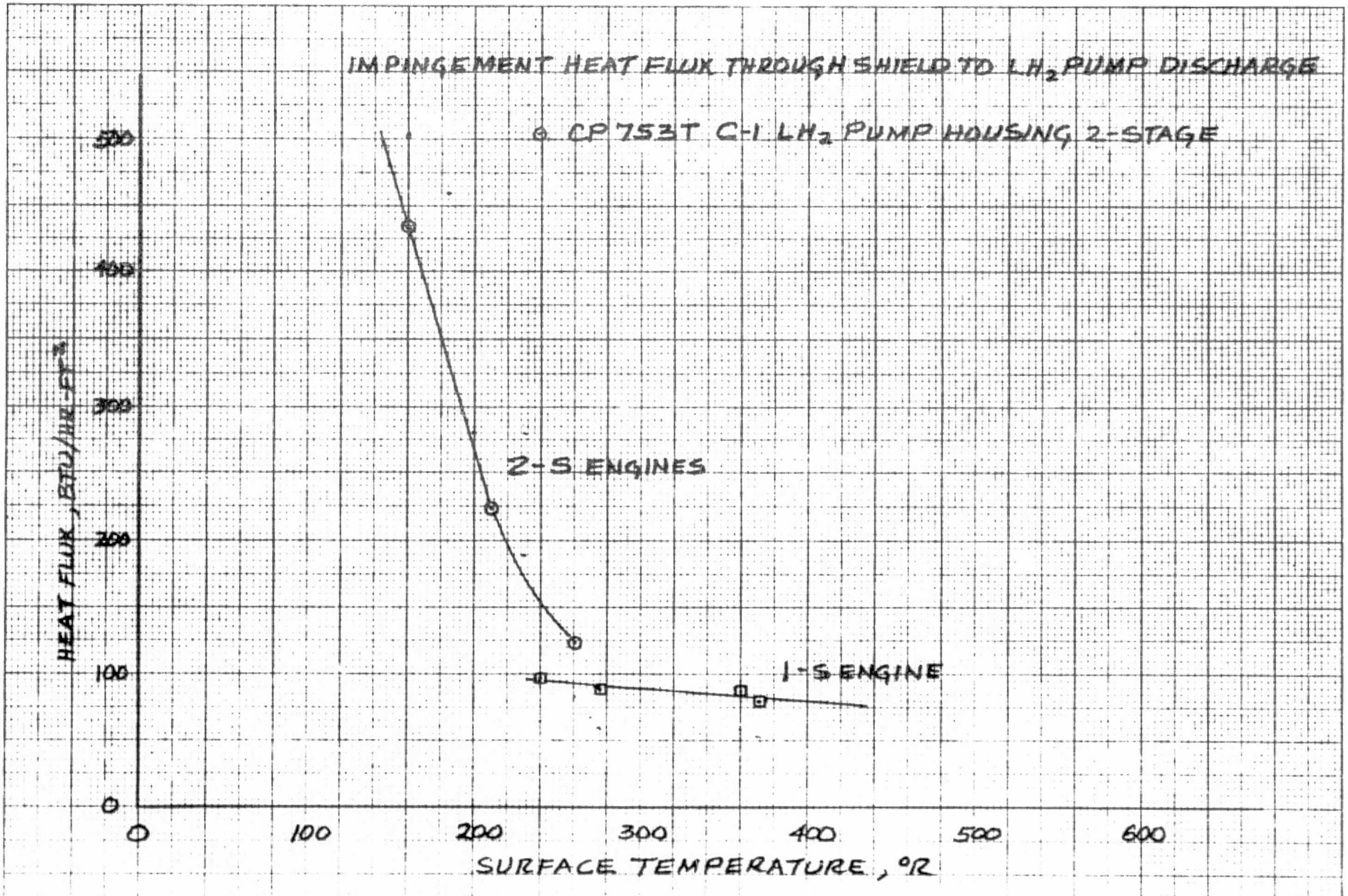




IMPINGEMENT HEAT FLUX AT STATION 2132 OUTBOARD ON BELL
CP741T C-1 ENGINE BELL S518 OTB
CP742T C-2 ENGINE BELL S518 OTB
IMPINGEMENT HEAT FLUX, BTU/HR-FT²
1000
800
600
400
200
0
2-S ENGINES
1-S ENGINE
200
300
400
500
600
700
SURFACE TEMPERATURE, °R


IMPINGEMENT HEATFLUX AT STATION 2146 INBOARD ON BELL
⊙ CP 743T C-1 ENGINE BELL S507 INB
CP 744T INVALID
IMPINGEMENT HEAT FLUX, BTU/HR-FT²
1000
800
600
400
200
0
200
300
400
500
600
700
SURFACE TEMPERATURE, °R
2-S ENGINES
1-S ENGINE


IMPINGEMENT HEAT FLUX THROUGH SHIELD TO LH_2 DISCHARGE/INLET LINE
CP752T C-1 LH_2 PUMP DISCHARGE LINE
CP754T C-1 LH_2 JACKET INLET LINE
HEAT FLUX, BTU/HR-FT^2
2-S ENGINES
S4B ?
S4A
1-S ENGINE
S4B
S4A
1-S ENGINE
0
100
200
300
400
100
200
300
400
500
600
700
800
DUCT SURFACE TEMPERATURE, °R



IMPINGEMENT HEAT FLUX THROUGH SHIELD TO LH_2 PUMP DISCHARGE
⊙ CP 753T C-1 LH_2 PUMP HOUSING 2-STAGE
2-S ENGINES
1-S ENGINE
HEAT FLUX, BTU/HR-FT²
SURFACE TEMPERATURE, °R
0
100
200
300
400
500
600

TABLE 12-IV. QUANTATIVE IMPINGEMENT FLUX ENVIRONMENT FROM S-ENGINES.

MEAS. NO.	DESCRIPTION	IMPINGE-MENT SOURCE	SURF TEMP	MEAS. FLUX	IMPINGE-MENT ANGLE	NORMAL FLUX	PLUME LOCATION AXIAL LEN.	PLUME LOCATION RADIAL	PREDICTION MACH NO.	PREDICTION HEAT FLUX	F*	BLOCKAGE
			°F	Btu/ HR-FT^2	DEG	Btu/ HR-FT^2	IN.	IN.		Btu/ HR-FT^2		
CP741T	C-1 ENG BELL	2-S-IV	-160	410	65	970	81	21	21	4100	.236	HELIUM BTL
	S518 OTB		> -30	100	65	238			21	500	.475	
		1-S-IV	> -30	59	65	141			>25	310	.455	
CP742T	C-2 ENG BELL	1-S-II IN ISA	> -30	123	65	289	81	21	>25	310	.930	
	S518 OTB	2-S-II	-160	935	65	2260			21	4100	.536	
			> -30	83	65	196			21	500	.392	
		1-S-II	> -30	54	65	128			>25	310	.412	
CP745T	C-1 ENG BELL	2-S-IV	-160	800	60	1600	58	26	19	8000	.200	HELIUM BTL
	S500 OTB		> -60	107	60	213			19	900	.237	
		1-S-IV	> -60	43	60	86			22	560	.153	
CP746T	C-2 ENG BELL	2-S-II	-160	1080	60	2160	58	26	19	8000	.270	
	S500 OTB		> -60	95	60	190			19	900	.211	
		1-S-II	> -60	36	60	72			22	560	.129	
CP743T	C-1 ENG BELL	1-S-II IN ISA	> -60	77	50	121	66	56		—		
	S507 INB	2-S-II	-160	685	50	1070			26	1430	.750	
			> -60	129	50	200			26	330	.605	
		1-S-II	> -60	79	50	122				—		

*RATIO OF MEASURED NORMAL FLUX TO PREDICTED FLUX.

TABLE 12-IV. QUANTITATIVE IMPINGEMENT FLUX ENVIRONMENT FROM S-ENGINES. (Contd)

MEAS. NO.	DESCRIPTION	IMPINGE-MENT SOURCE	SURF TEMP	MEAS. FLUX	IMPINGE-MENT ANGLE	NORMAL FLUX	PLUME LOCATION AXIAL LEN.	PLUME LOCATION RADIAL	PREDICTION MACH NO.	PREDICTION HEAT FLUX	F*	BLOCKAGE
			°F	Btu/HR-FT^2	DEG	Btu/HR-FT^2	IN.	IN.		Btu/HR-FT^2		
CP752T	C-1 LH_2 PUMP DISCH LINE	2-S-IV	-160	270	10	274	30	20	18	3200	.086	UNDERSHLD
		1-S-IV	ALL	135	10	137				—		"
CP754T	C-1 LH_2 JKT INLET LINE	2-S-IV	-160	160	45	226	34	24	195	2500	.091	UNDERSHLD
		1-S-IV	ALL	55	45	78				—		"
CA304T	LO_2 DUCT OUTER RAD SHIELD	2-S-IV	-60 to 175	425	60**	850	22	24	24	720	1.180	
		1-S-IV	-60 to 175	270	60**	540				—		
CP159T	QD4 LH_2 B/P H_2O_2 LINE	2-S-IV	100 to 150	185	65**	438	21	35	35	260	1.68	
		1-S-IV	125 to 175	97	65**	230				—		
CP929T	C-2 ENG PUMP SHIELD	1-S-II IN ISA	-180	685	50	1060	26	37	29	950	1.120	
		2-S-II	-160	352	50	550			27	—		
			>-110	261	50	408			27	450	.910	
		1-S-II	<-110	220	50	344			29	950	.361	UMBILICAL ISLAND

*RATIO OF MEASURED NORMAL FLUX TO PREDICTED FLUX.

**PLUME INTERACTION WITH OBSTRUCTING BOTTLES AND STRUCTURE AND RESULTANT ADJACENT SHOCKS MAKES FLOW DIRECTION ILL DEFINED.

TABLE 12-V. COMPARISON OF IMPINGEMENT HEATING ON WARM COMPONENTS DURING SPACE COAST.

MEAS. NO.	COMPONENT	IMPINGEMENT SOURCE	PLUME LOCATION		AVG RISE RATE OVER PROLONGED INTERVAL		
			LENGTH IN.	RADIAL IN.	1 ENG °F/MIN.	2 ENG °F/MIN.	
CH9T	C-1 RECIRC MTR HSG	S-IV ENGINES (SUN)	38	22	—	0.4	LITTLE IMPINGEMENT, RISE DUE TO SOLAR HEATING
CH10T	C-2 RECIRC MTR HSG	S-II ENGINES (NO SUN)	38	22	0.5	1.5	AGREES WITH 1.7 °F/MIN. TOTAL RISE RATE OF 988-3-71-90 (REF 34) FOR IMPINGEMENT.
CU240T	C-1 SERVOPOSITIONER	S-IV ENGINES (SUN)	30	27	0	0	IMPINGEMENT IS BLOCKED BY He BOTTLE.
CU241T	C-2 SERVOPOSITIONER	S-II ENGINES (NO SUN)	30	27	0 70°F EQUIL. TEMP.	2.5	AGREES WITH 2.4 °F/MIN. TOTAL RISE RATE OF 988-3-71-90 (REF 34)
CF15T	NO. 2 HELIUM BTL TEMP	S-IV ENGINES (NO SUN)	19	13	1.4 AVG FOR 1ST COAST*		AGREES WITH AVERAGE 1.7 °F/MIN. AT PROBE LOCATION DURING 1ST COAST FROM 965-4/HT73/006 (REF 61).

*SUBSEQUENT MAX TEMPERATURES (WITH EMPTY BOTTLE) OF 125°F DURING 2ND COAST IS DUE TO CONDUCTION SOAKOUT FROM INSULATION AND HOT SPOT, 150°F DURING 3RD COAST DUE TO CONDUCTION SOAKOUT OF ACCUMULATED SOLAR HEATING, 5.5 °F/MIN. MAX RISE DURING H_2O_2 DEPLETION EXPERIMENT DUE TO SOAKOUT OF ACCUMULATED SPACE HEATING AND 2-ENGINE IMPINGEMENT PLUS SUN.

THERMAL AND HEAT TRANSFER

- LO_2 TANK SHIELD INSULATION KIT
  - THERMAL RESPONSE AND LO_2 TANK FLIGHT HEAT RATES
- INTERMEDIATE BULKHEAD PERFORMANCE FROM PROPELLANT ENERGY BALANCES
- TANK VENT SYSTEMS
  - THERMAL RESPONSE
- ELECTRONIC EQUIPMENT
  - THERMAL RESPONSE AND PERFORMANCE
- HYDRAULIC SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE
- H_2O_2 SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE
- H_2O_2 SYSTEM EXHAUST IMPINGEMENT HEATING ENVIRONMENT
- MAIN PROPULSION SYSTEM
  - THERMAL RESPONSE AND PERFORMANCE
- THERMAL CONTROL SUMMARY

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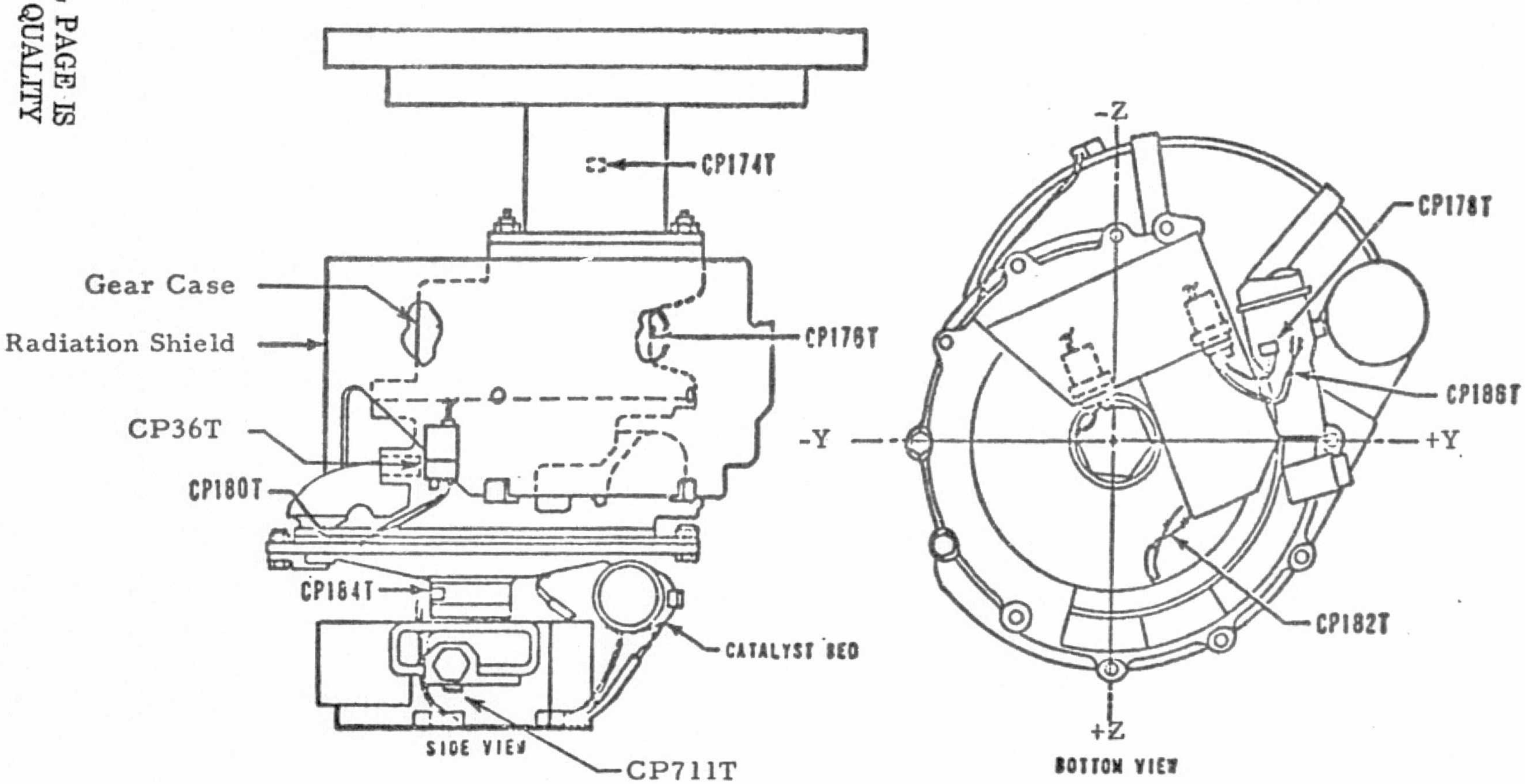
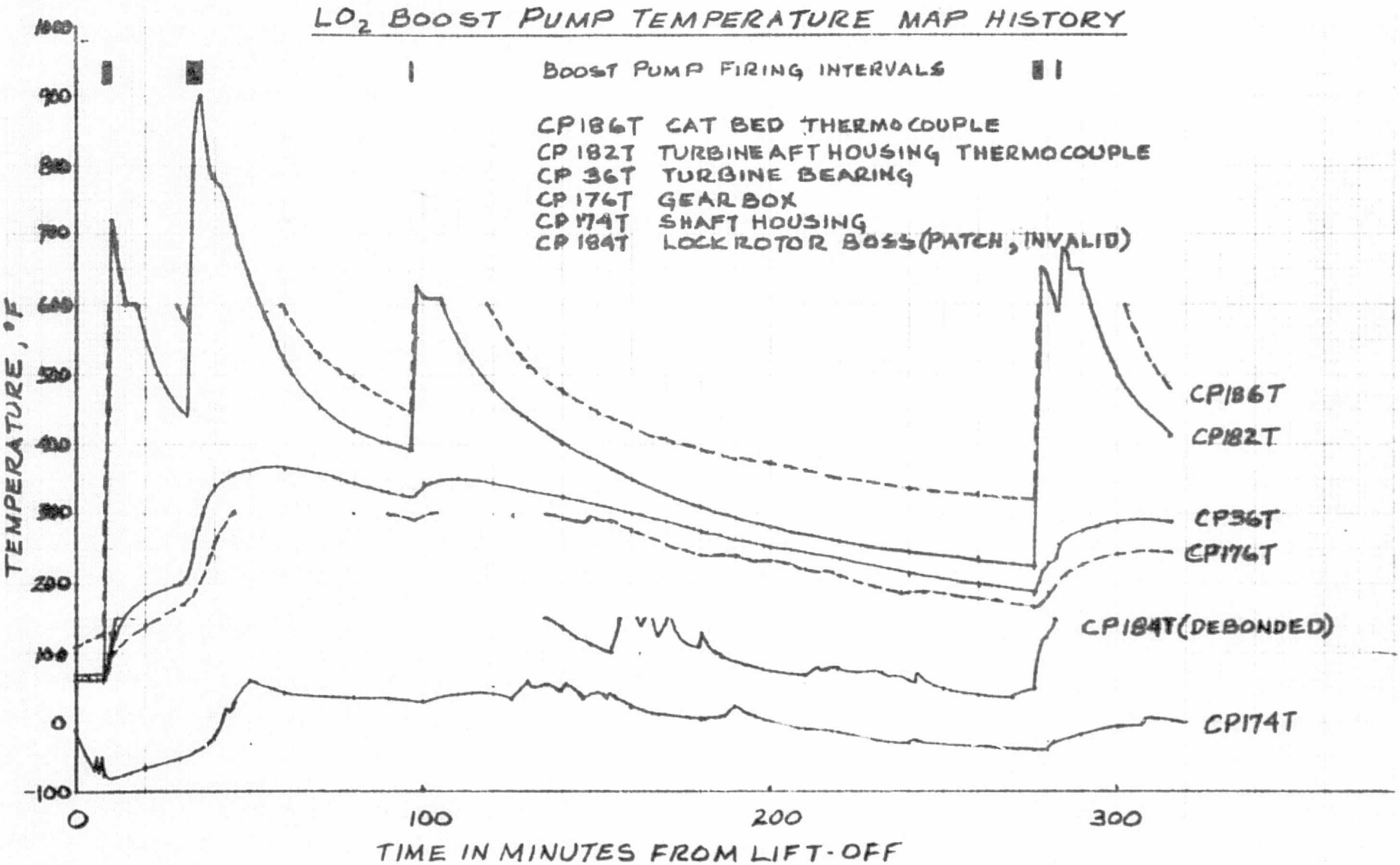
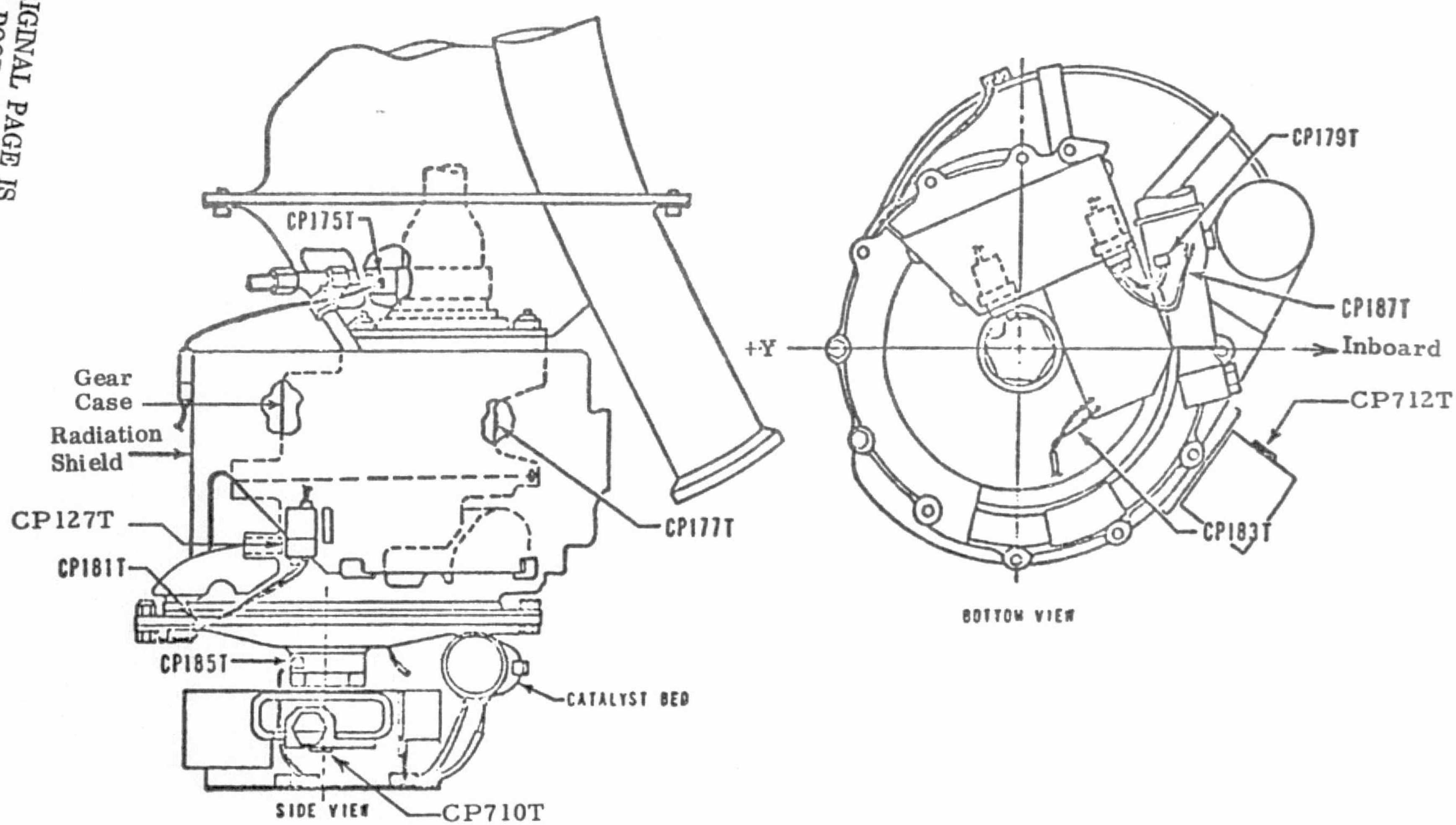
FIGURE 13-1. CENTAUR LO_2 BOOST PUMP TEMPERATURES.





LO2 BOOST PUMP TEMPERATURE MAP HISTORY
BOOST PUMP FIRING INTERVALS
CP186T CAT BED THERMOCOUPLE
CP 182T TURBINE AFT HOUSING THERMOCOUPLE
CP 36T TURBINE BEARING
CP 176T GEAR BOX
CP 174T SHAFT HOUSING
CP 184T LOCK ROTOR BOSS (PATCH, INVALID)
CP186T
CP182T
CP36T
CP176T
CP184T (DEBONDED)
CP174T
TEMPERATURE, °F
1000
900
800
700
600
500
400
300
200
100
0
-100
0
100
200
300
TIME IN MINUTES FROM LIFT-OFF

FIGURE 13-2. CENTAUR LH_2 BOOST PUMP TEMPERATURES.



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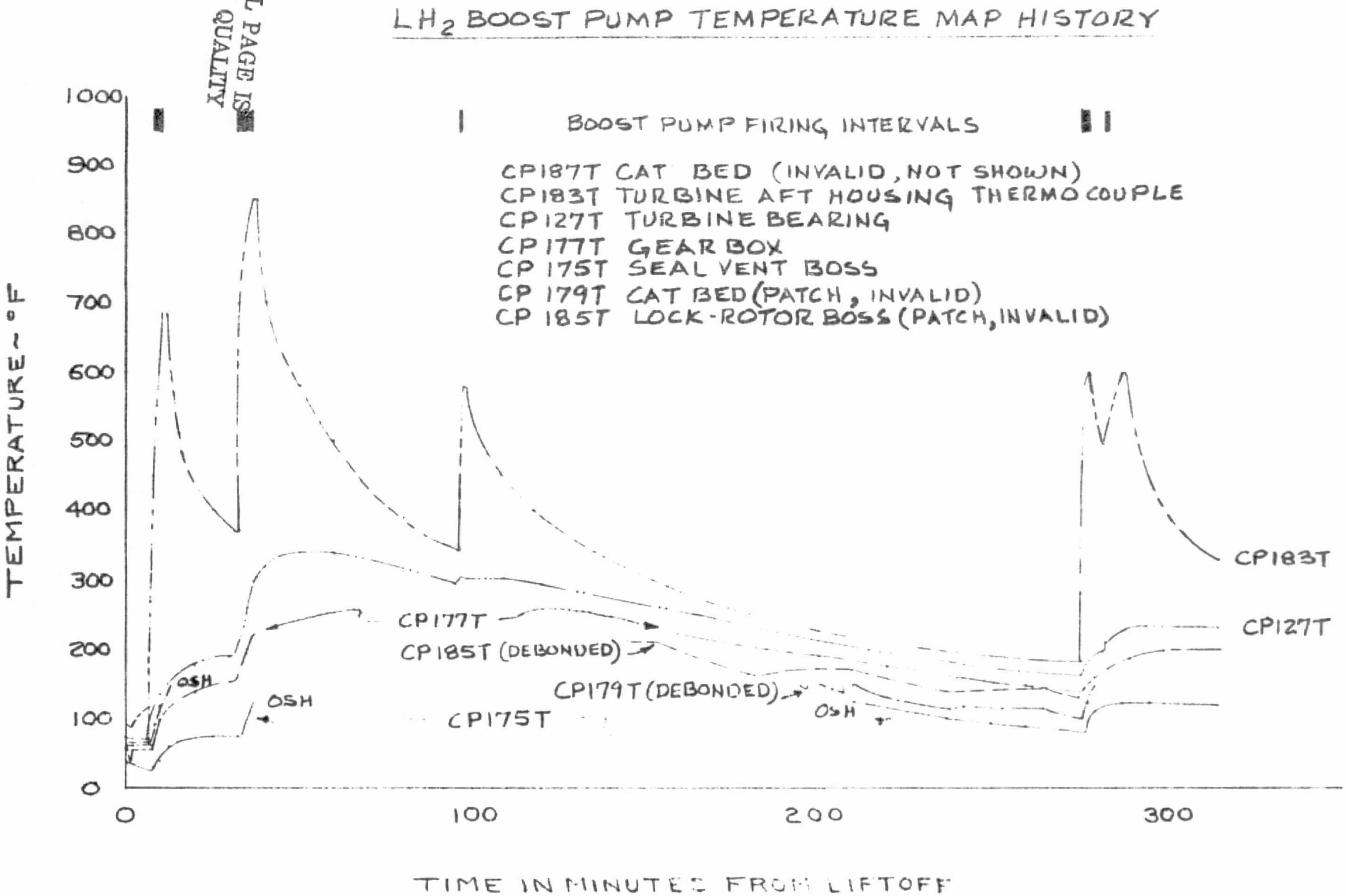

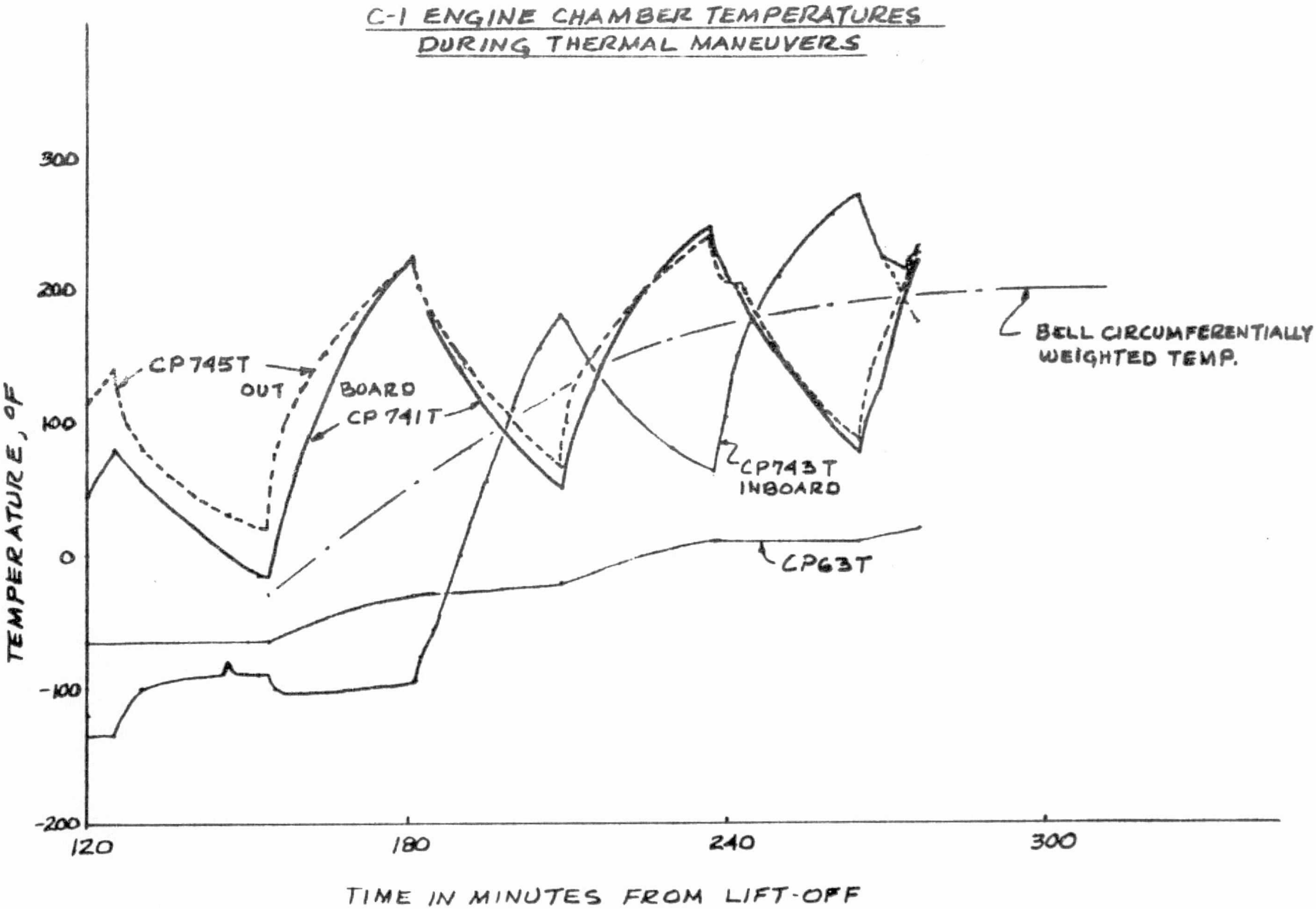
C-1 ENGINE CHAMBER TEMPERATURES
DURING THERMAL MANEUVERS
300
200
100
0
-100
-200
120
180
240
300
TEMPERATURE, °F
TIME IN MINUTES FROM LIFT-OFF
CP745T
OUT
BOARD
CP741T
CP743T
INBOARD
CP63T
BELL CIRCUMFERENTIALLY
WEIGHTED TEMP.

ENGINE CHAMBER WEIGHT AND CIRCUMFERENTIAL AVERAGE
TEMPERATURE VERSUS LONGITUDINAL DISTANCE

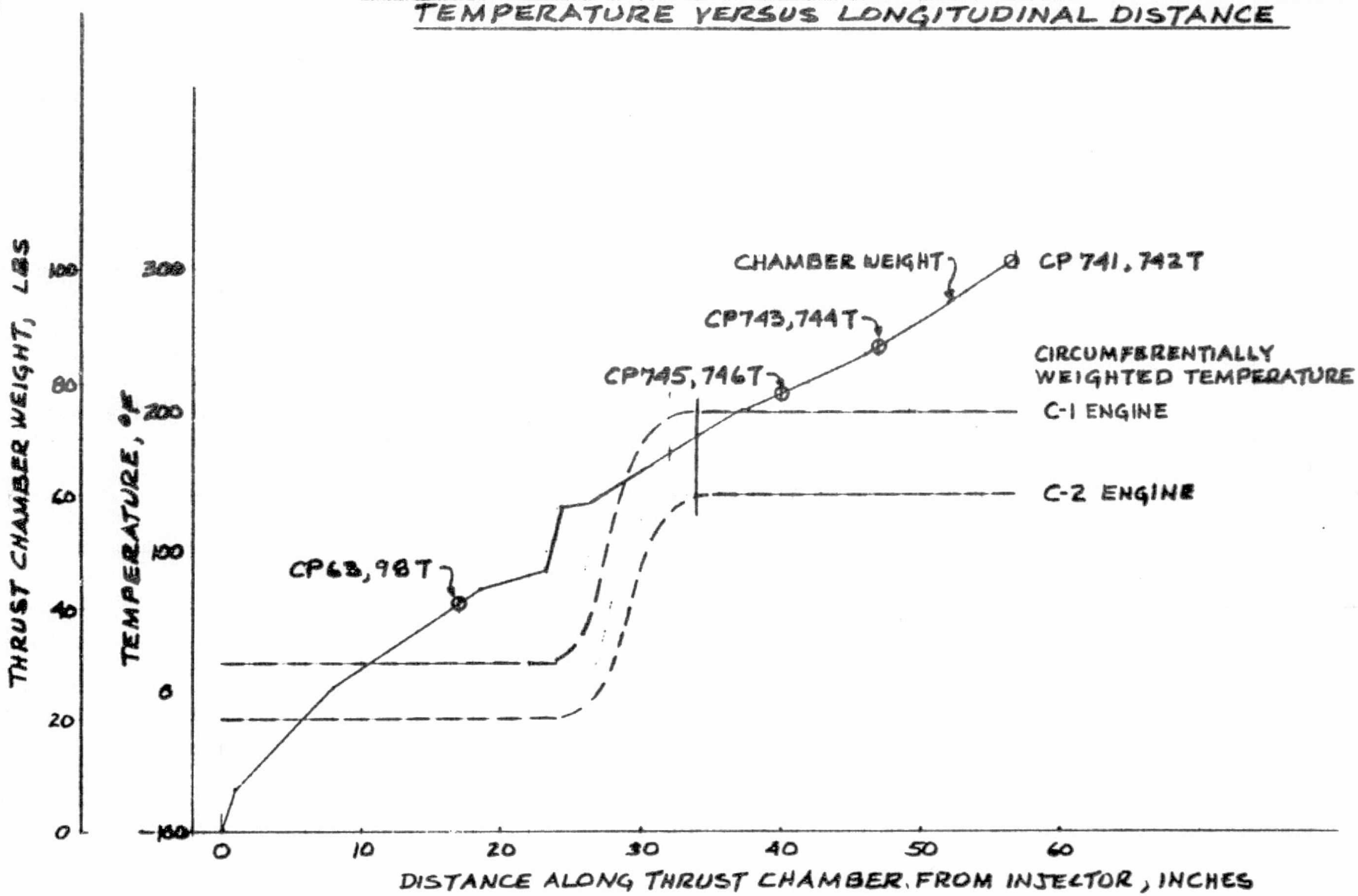

TABLE 13-1. MAXIMUM ENGINE WEIGHTED TEMPERATURES

PORTION OF CHAMBER	WEIGHT LB	C-1 ENGINE T °F	C-1 ENGINE C_P BTU/LB °F	C-1 ENGINE MC_P BTU/°F	C-1 ENGINE MC_PT BTU	C-2 ENGINE T °F	C-2 ENGINE C_P BTU/LB °F	C-2 ENGINE MC_P BTU/°F	C-2 ENGINE MC_PT BTU
COMBUSTION CHAMBER/THROAT LH_2 INLET MANIFOLD	58	20	0.105	6.08	121.8	-20	.101	5.86	117.2
TRANSITION ZONE	13	120	0.111	1.44	173.0	50	.107	1.39	69.5
BELL	31	200	0.114	3.54	708.0	140	.112	3.47	485.0
TOTAL	102			11.06	1002.8			10.72	671.7
WEIGHTED TEMP $= \frac{\Sigma MC_PT}{\Sigma MC_P}$		91				63			

MAXIMUM ALLOWABLE WEIGHTED AVERAGE TEMPERATURE = 110°F (570°R)

CENTAUR ENGINE TEMPERATURES
RPT 988-3-71-90 PREDICTED AND TC-2 FLIGHT DATA
CONTINUOUS SETTLED COAST

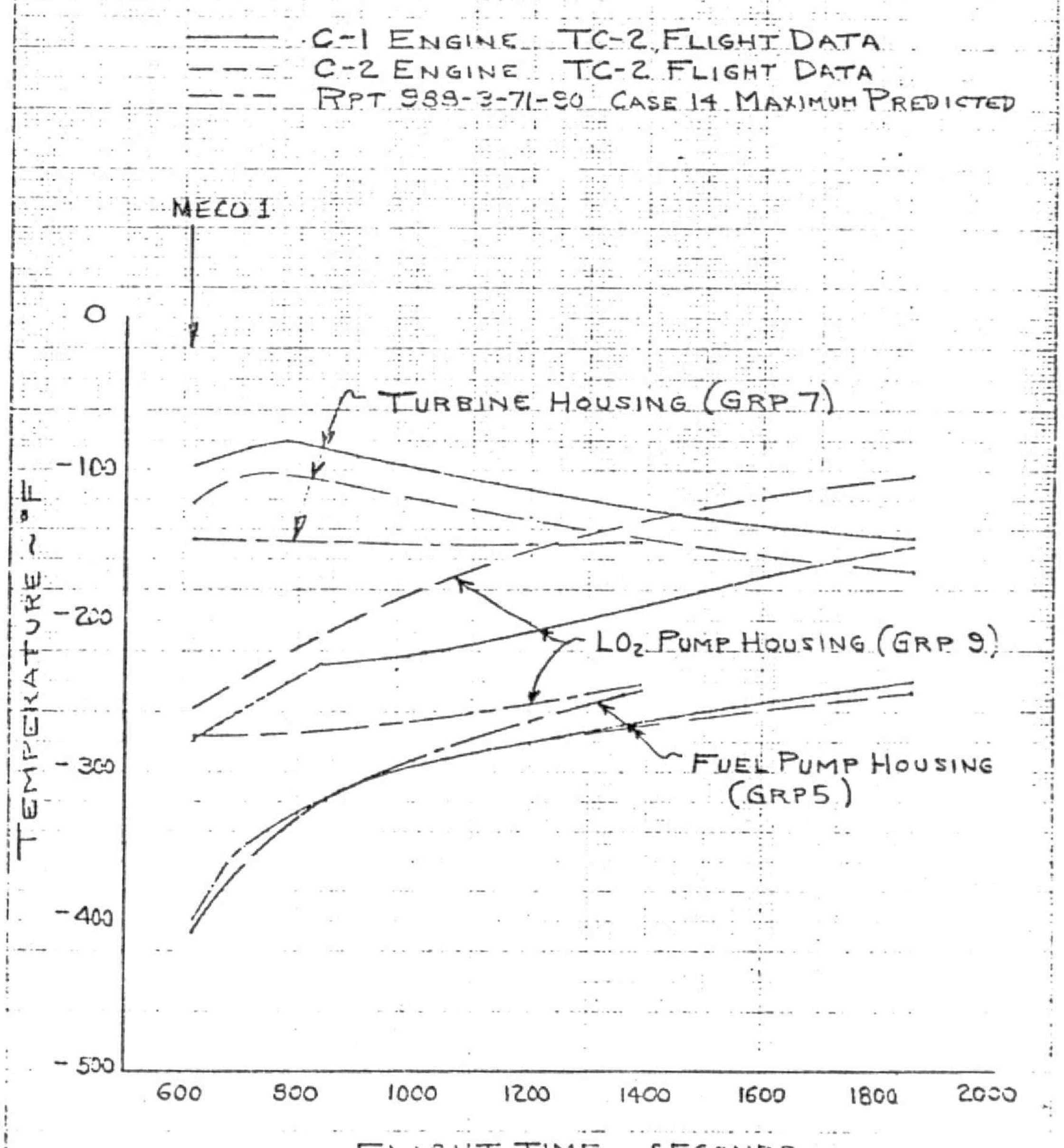

FIGURE 13-10

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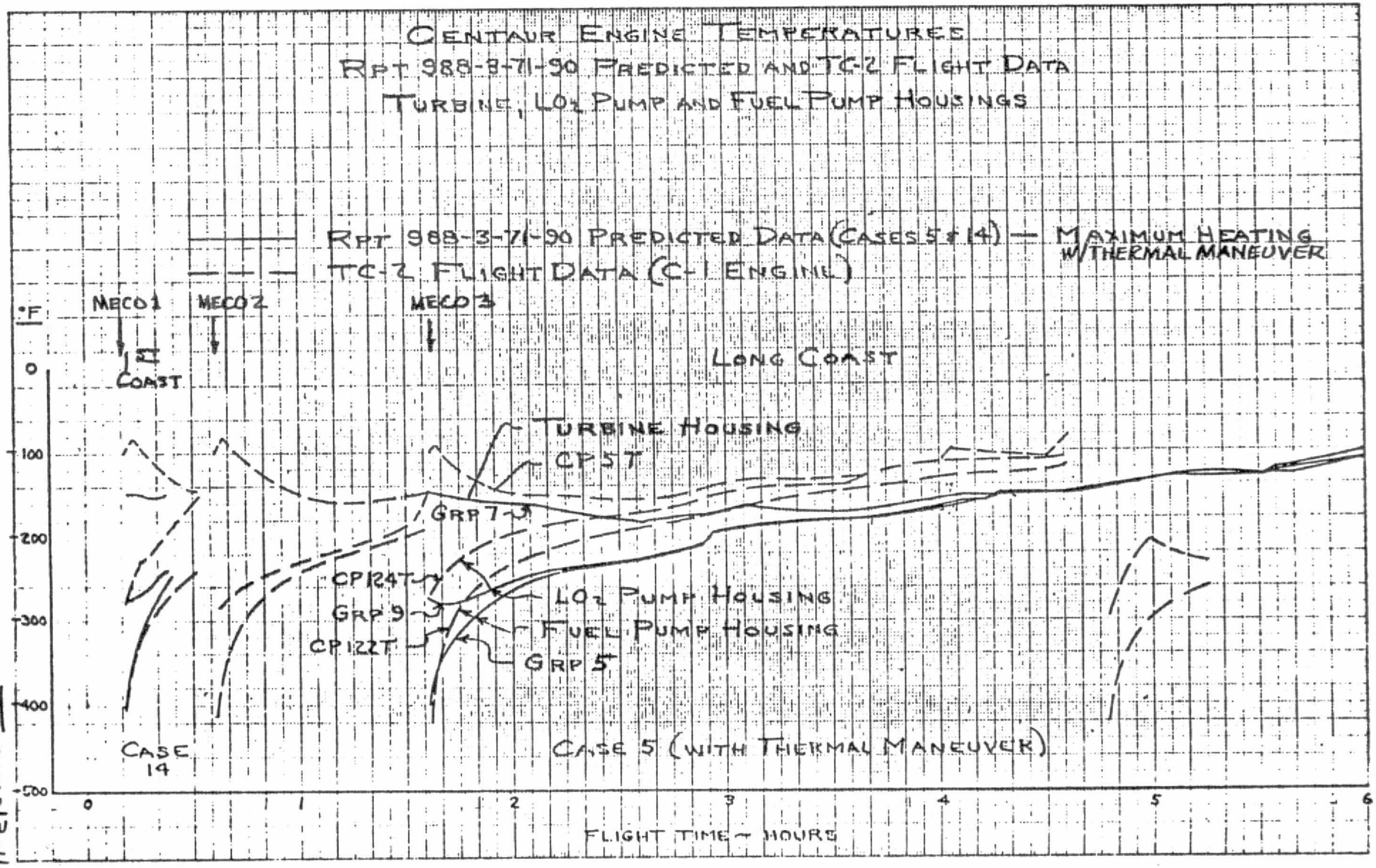

FIGURE 13-11

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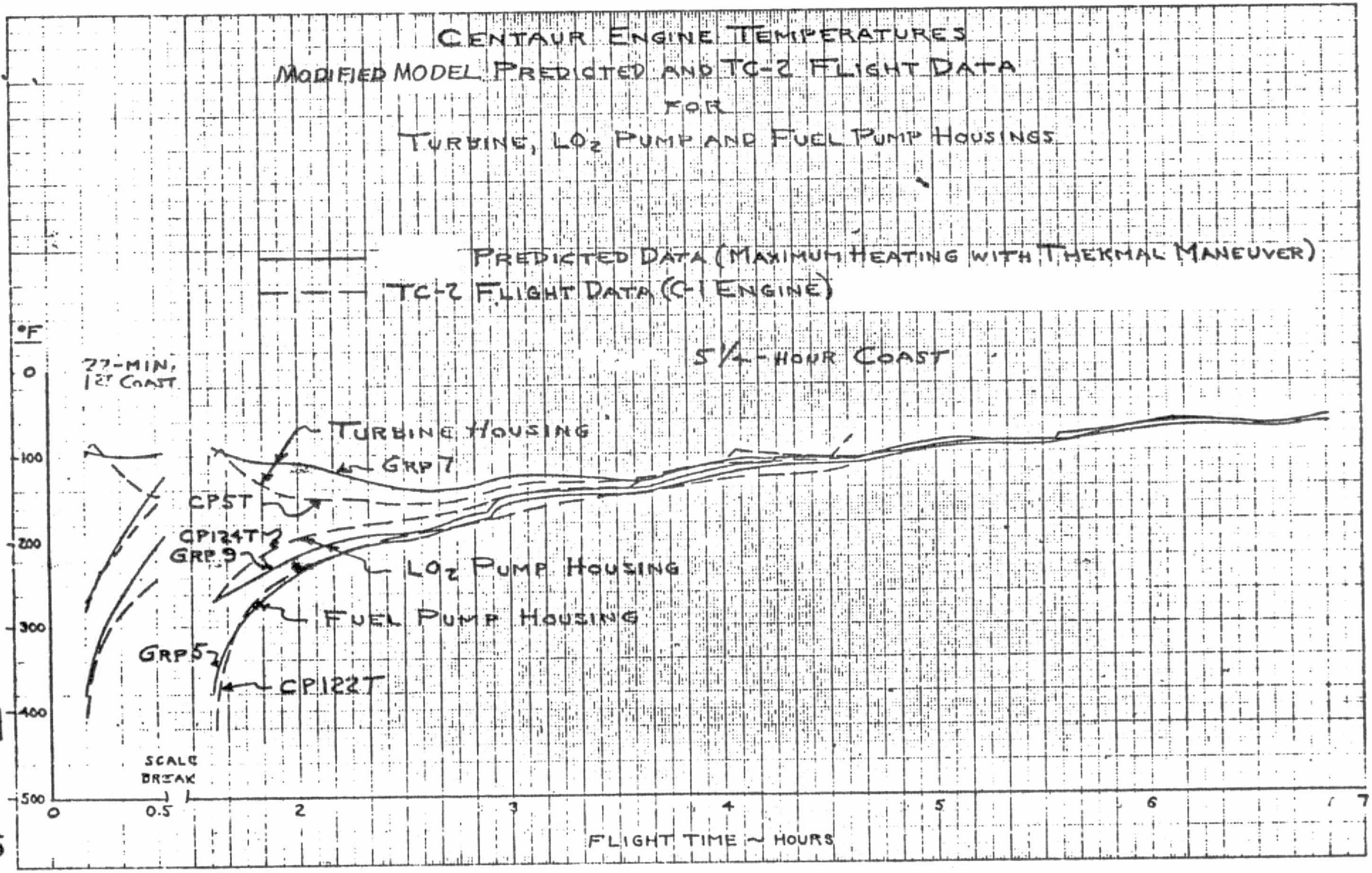


FIGURE 13-12

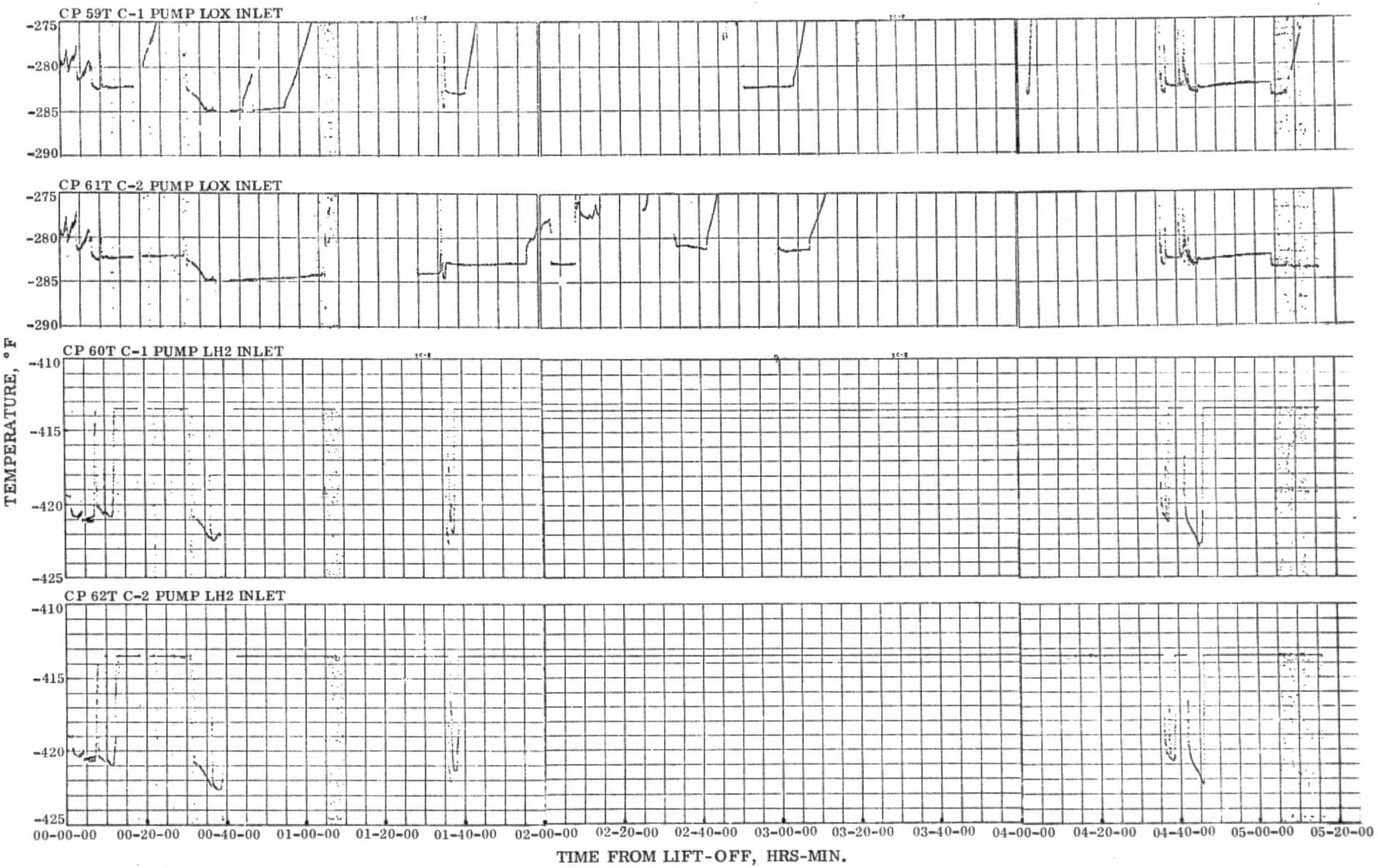
SUMMARY COMPARISON OF PROPULSION SYSTEM TEMPERATURES (°R)

TC-5 Mission →	1 st Settled Coast				1 1/2 Hr Backup 0-G Orbit				5 1/4 Hr 0-G Coast		30 Min 0-G Coast		20 Min 0-G Coast		5 Min 0-G Coast		2 Hr 0-G Coast	
	14 Min		35 Min		96 Min		125 Min											
Item Description	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
TC-2 Configuration Predictions																		
Fuel Duct Weighted	125	84	176	99	186	130	208	149	287	205	128	87	112	78	97	70	205	147
Oxidizer Duct Weighted	188	175	215	175	209	185	222	189	295	198	187	177	182	175	175	175	222	188
Group Node:																		
5 Fuel Turbopump Housing	225	180	325	245	308	213	318	233	392	285	238	182	210	167	160	132	313	233
9 Oxidizer Turbopump Housing	292	198	398	206	315	223	323	236	397	267	254	192	233	187	233	190	320	235
7 Turbine Housing	362	300	371	289	337	244	334	249	398	282	345	278	347	288	363	310	328	250
5 or 6 Fuel Duct @ CP751T	200				228		249		331 279†		182		177		180		246	
43 Oxidizer Duct @ CP750T	193				201		217		294 241†		183		180		175		214	
Prestart Times (Seconds)																		
Reference 81 LO_2	9	<9	17	<9	9	<9	11	<9	17	<9	<9	<<9	<<9	<<9	<<9	<<9	11	<<9
LH_2	<9	<9	11	<9	9	<<9	11	<<9	20	9	<9	<<9	<<9	<<9	<<9	<<9	11	<<9
Reference 82 LO_2	7	<7	17	<7	7	<<7	9	<7	11	<7	<7	<<7	<<7	<<7	<<7	<<7	9	<<9
LH_2	7	<7	11	<7	9	<<7	11	<<7	17	<7	<7	<<7	<<7	<<7	<<7	<<7	11	<<9
Minimum Prestart Time	17				11				20		7		7		7		11	
TC-2 Data			22 Min						3 Hr									
Engine	C-1	C-2	C-1	C-2	C-1	C-2	C-1	C-2	C-1	C-2	C-1	C-2	C-1	C-2	C-1	C-2	C-1	C-2
Fuel Turbopump Housing	196	200	215	220	300	270	320	295	340	330	230	220	212	205	150	150	315	290
Oxidizer Turbopump Housing	276	330	310	360	317	285	332	315	380	390	240	240	225	230	231	265	328	312
	(231)*	(253)*	(247)*	(264)*					(365)*	(368)*					(208)*	(226)*		
Turbine Housing	332	310	315	295	325	290	335	310	355	340	305	285	320	300	370	345	330	310
C-1 Fuel Duct @ CP751T	120		150		265		285		300		95		82		<60		282	
C-1 Oxidizer Duct @ CP750T	185		200		245		260		280		180		180		185		255	

* Temperatures in ( ) are adjusted from the probe indicated temperature for gradients and probe thermal resistance effects during impingement heating to yield more realistic LO_2 pump mass temperatures.

† 3 Hr 0-G Coast

ENGINE INLET PROBE TEMPERATURES DURING FLIGHT



THERMAL AND HEAT TRANSFER

- LO_2 TANK SHIELD INSULATION KIT
  - — THERMAL RESPONSE AND LO_2 TANK FLIGHT HEAT RATES
- INTERMEDIATE BULKHEAD PERFORMANCE FROM PROPELLANT ENERGY BALANCES
- TANK VENT SYSTEMS
  - — THERMAL RESPONSE
- ELECTRONIC EQUIPMENT
  - — THERMAL RESPONSE AND PERFORMANCE
- HYDRAULIC SYSTEM
  - — THERMAL RESPONSE AND PERFORMANCE
- H_2O_2 SYSTEM
  - — THERMAL RESPONSE AND PERFORMANCE
- H_2O_2 SYSTEM EXHAUST IMPINGEMENT HEATING ENVIRONMENT
- MAIN PROPULSION SYSTEM
  - — THERMAL RESPONSE AND PERFORMANCE
- THERMAL CONTROL SUMMARY

THERMAL CONTROL SUMMARY

- PRELAUNCH PURGING AND GAS CONDITIONING PROVIDED SATISFACTORY THERMAL CONTROL OF EQUIPMENT AND PAYLOAD.

- INSULATIONS, NEW HEAT TRANSFER ATTENUATING STRUCTURE, AND THE NEW 3-LAYER RADIATION SHIELD SYSTEMS PERFORMED WITHIN PREDICTIONS PROVIDING EXCELLENT THERMAL PROTECTION OF CRYOGENS DURING SPACE OPERATIONS.

- ASCENT THERMODYNAMIC AND VENTING ENVIRONMENTS AND RESPONSES WERE WITHIN PREDICTIONS AND CONFIRMED THE ACCEPTABILITY OF H_2O_2 ENGINE FIRING WITHIN THE ISA.

- TANK VENT SYSTEMS THERMAL RESPONSE AND CONTROL WAS SATISFACTORY. SECOND TITAN/CENTAUR FLIGHT CONFIRMED LO_2 VENTING DURING AND AFTER PERIODS OF TANK PRESSURE AND ACCELERATION COMBINATIONS CONDUCIVE TO BULK BOILING OF THE LO_2 WHICH PUSHES LIQUID BULK FORWARD WITH SPILLAGE INTO THE STAND PIPE.

- THERMAL CONTROL OF EQUIPMENT WAS SATISFACTORY DURING SPACE OPERATIONS OF TC-2 DURATIONS. OVERHEATING TRENDS WERE DEVELOPING ON THE DCU AND S-BAND TRANSMITTER AGGRAVATED BY SOLAR ENTRAPMENT AND RERADIATION OBSTRUCTION BY THE HELIOS ENVIRONMENTAL SHIELD, LOCAL HIGH DENSITY OF "HOT" PACKAGES, AND THERMAL MANEUVER WITH REPEATED, MAXIMUM SOLAR ASPECT ON ALTERNATE ROLLS.

- HYDRAULIC SYSTEM THERMAL CONTROL WITH 3-LAYER RADIATION SHIELD BOOTS WAS SATISFACTORY.

THERMAL CONTROL SUMMARY

- H_2O_2 SYSTEM THERMAL CONTROL WAS SATISFACTORY WITH HEATED LINES AND 3-LAYER SHIELD BOOTS ON UNHEATED SECTIONS AND FITTINGS. REDUNDANT PARALLEL FLOW FEATURE WAS NOT EXERCISED. "HOT" ZONES DEVELOPED ON HEATED LINES IN RADIATION TRAPPED LOCATIONS COMBINED WITH MAXIMUM DIRECT AND VEHICLE REFLECTED SOLAR RADIATION.

- "FREE" PLUME IMPINGEMENT HEATING RATES TO SURFACES AND EXPOSED COMPONENTS WERE WITHIN PREDICTIONS. HEATING RATES WERE SOMETIMES HIGHER THAN PREDICTED IN PLUMES SUBJECTED TO DEFLECTION, COMPRESSION, OR SHOCK INTERACTION BY ADJACENT VEHICLE SURFACES.

- ENGINE IMPINGEMENT SHIELDS WERE LESS EFFECTIVE THAN ASSUMED DUE TO GREATER INFLOW AND CONDUCTIVE/CONVECTIVE DEGRADATION BY H_2O_2 EXHAUST PRODUCTS.

- TEMPERATURE RISE ON THE LO_2 TURBOPUMP DURING COASTS WAS HIGHER THAN PREDICTED DUE TO A COMBINATION OF WARMER TURBINE AT MECO, HIGHER IMPINGEMENT SHIELD HEAT TRANSFER DEGRADATION, MAXIMUM SOLAR ASPECT TO THE SUN AND REFLECTION FROM THE ENGINE CHAMBER. ENVIRONMENT/THERMAL MODEL MODIFICATION ACHIEVED PREDICTIVE AGREEMENT WITH FLIGHT DATA.

- ENGINE CHAMBER BELLS LOCALLY HEATED HIGHER THAN PREDICTED FOR DIRECT SOLAR IMPINGEMENT DUE TO UNIDENTIFIED NICKEL SPLASH COAT. CHAMBER WEIGHTED AVERAGE TEMPERATURE FOR LONG SPACE COAST SATISFIES 570°R MAXIMUM ALLOWABLE FOR RESTART.

THERMAL CONTROL SUMMARY

- BOOST PUMP THERMAL RESPONSE AND CONTROL WAS SATISFACTORY AND WITHIN PREDICTIONS INCLUDING EXTRAPOLATION OF RESPONSE TO 5-1/4 HOUR COAST.

- MAIN PROPELLANT DUCTS WITH 3-LAYER RADIATION SHIELDING RETAINED PARTIAL LIQUID FOR MOST, IF NOT ALL, OF COAST CONTRIBUTING TO WEIGHTED AVERAGE TEMPERATURE WITHIN PREDICTIONS AND PRESTART DURATIONS WITH SIGNIFICANT MARGIN.

- ADVERSE OVERHEAT TREND DURING LONG COASTS WITH VEHICLE HIGH DENSITY EQUIPMENT COMPLEMENT TO BE ALLEVIATED BY PRECESSING THERMAL MANEUVER.

GENERAL DYNAMICS
Convair Division
31 Oct 75

TC-2 POST HELIOS EXPERIMENT DATA REVIEW

I	INTRODUCTION	HUBER
II	PROPELLANT BEHAVIOR	MERINO
III	HELIUM USAGE	MERINO
IV	PROPELLANT TANK PRESSURIZATION	MERINO
V	PROPELLANT TANK THERMODYNAMICS	MERINO
VI	COMPONENT HEATING & THERMAL CONTROL	CHRISTENSEN
VII	MAIN ENGINE SYSTEM	HUBER
VIII	H_2O_2 CONSUMPTION	HUBER
IX	BOOST PUMP POST-MECO PERFORMANCE	HUBER/MERINO
X	OVERVIEW OF OTHER SYSTEMS	HUBER

MAIN ENGINE PERFORMANCE

- All important engine parameters indicated normal operating conditions during the 3rd and 4th burns.

MAIN ENGINE PERFORMANCE PARAMETERS

Meas No.	Description	Units	Burn No. 1		Burn No. 2*	Burn No. 3		Burn No. 4		Typ "D" Centaur	
			MES1	MECO1	MECO2	MES3	MECO3	MES4	MECO4	MES2	MECO2
CP46P	C1 Thrust Chamber Press	psia	2	392	396	2	398	2	394	0	388
CP1B	C1 Pump Speed	rpm	0	12300	12240	0	12300	0	12610	0	12300
CP7P	C1 Fuel Venturi Inlet Press	psia	16	744	756	16	760	16	771	16	740
CP107P	C1 LO_2 Pump Discharge Press	psia	118	605	601	115	611	115	637	115	611
CP194P	C1 LH_2 Pump Discharge Press	psia	24	990	996	18	1002	24	1025	†	†
CP5T	C1 Turbine Inlet Temp	°F	-73	-65	-64	-108	-66	-96	-105	-136	-81
CP47P	C2 Thrust Chamber Press	psia	4	396	398	4	398	4	396	2	388
CP2B	C2 Pump Speed	rpm	0	12240	12180	0	12000	0	12610	0	12300
CP8P	C2 Fuel Venturi Inlet Press	psia	16	723	727	12	723	12	744	20	760
CP108P	C2 LO_2 Pump Discharge Press	psia	112	598	592	109	605	109	630	109	608
CP195P	C2 LH_2 Pump Discharge Press	psia	29	965	971	24	972	24	1007	†	†
CP6T	C2 Turbine Inlet Temp	°F	-68	-88	-87	-171	-91	-116	-121	-136	-79

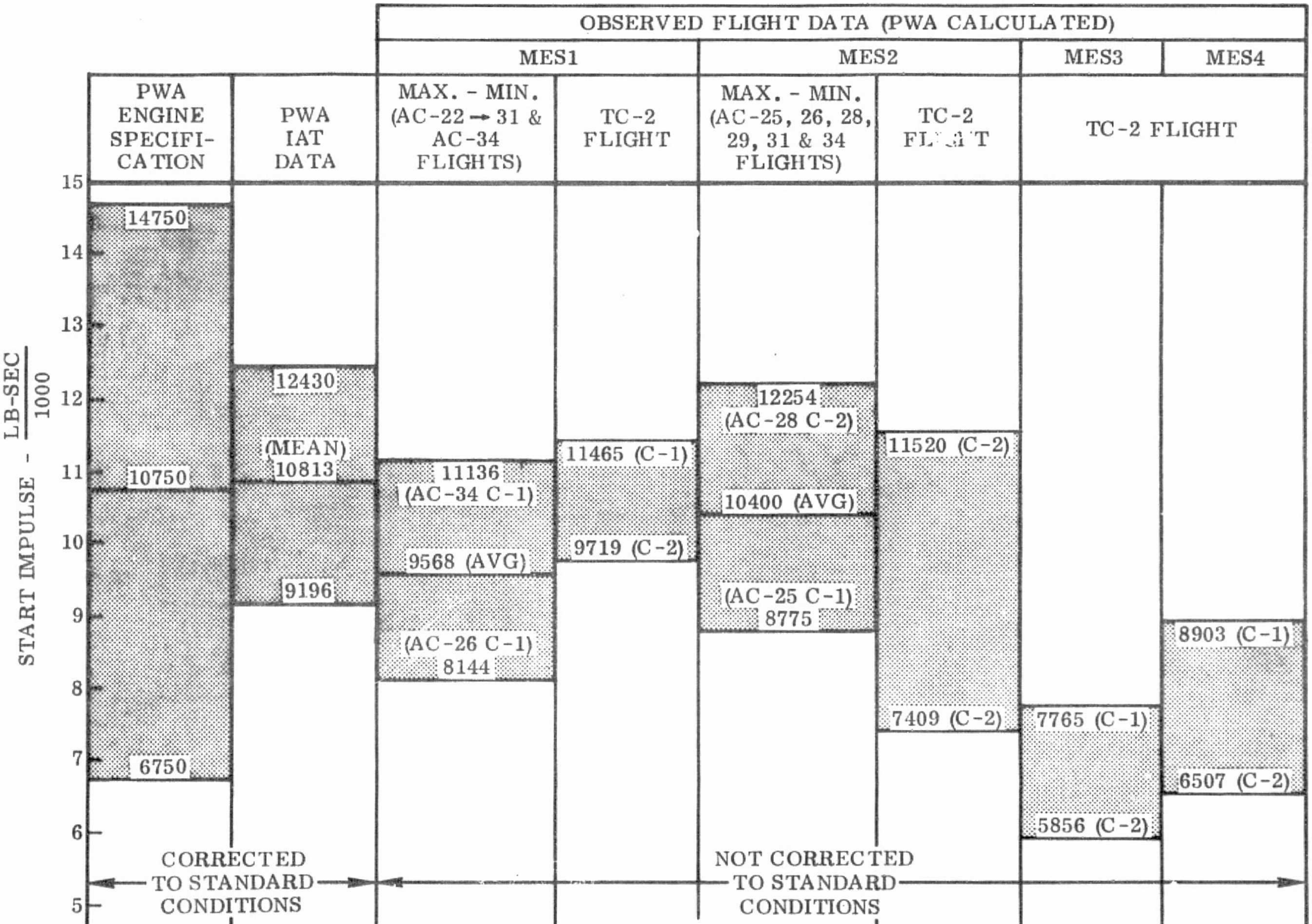
* MES2 Data Not Available

† Data Not Available

MAIN ENGINE START PERFORMANCE

- Slower accelerating engines resulted in reduced start impulse during the 3rd and 4th start transients.
- C-2 engine start impulse was lowest of all flights to date.

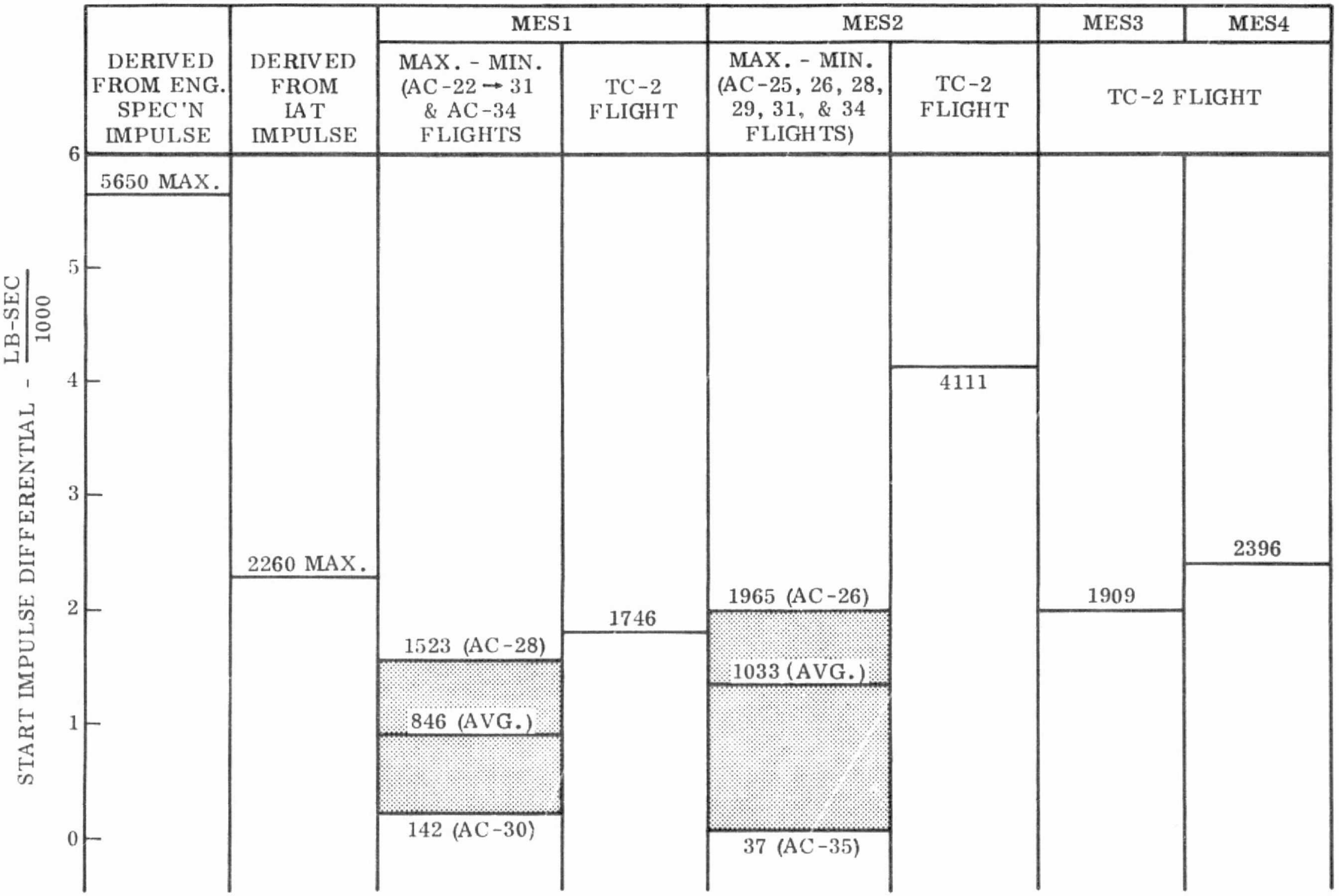
START IMPULSE SUMMARY (PER ENGINE)



START IMPULSE DIFFERENTIAL

- The slower accelerating C-2 engine resulted in large (but acceptable) start impulse differentials.

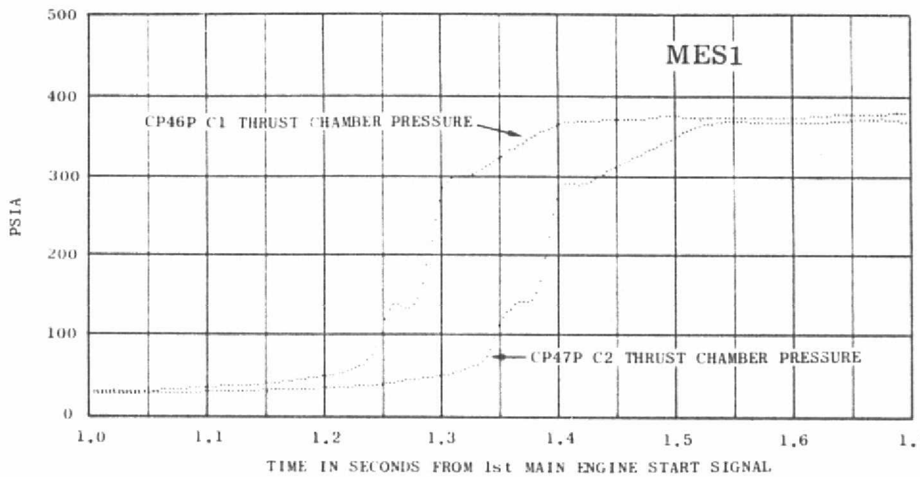
START IMPULSE DIFFERENTIAL – SUMMARY

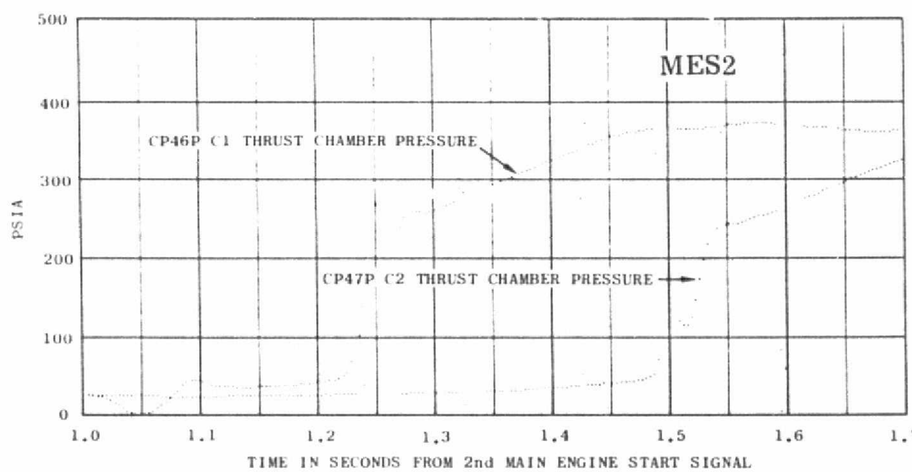


START IMPULSE DIFFERENTIAL EFFECTS

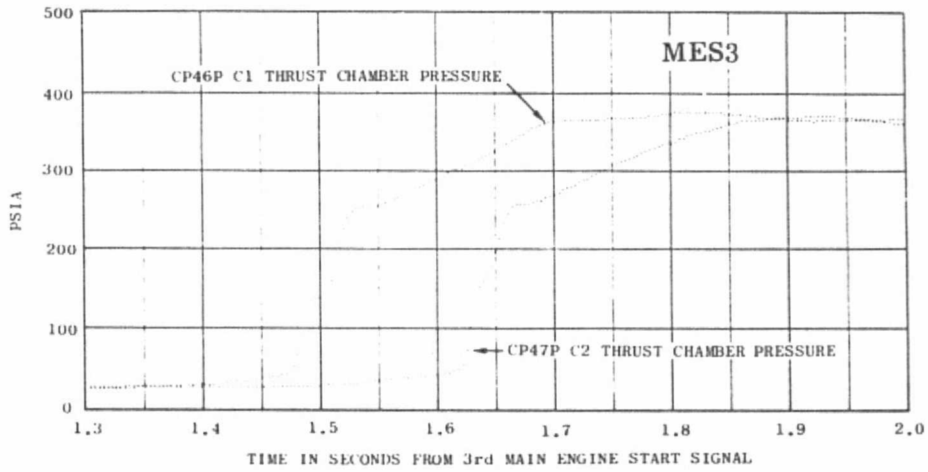
	MAXIMUM VEHICLE TURNING RATES DURING ENGINE IGNITION TRANSIENT — DEGREES PER SECOND			MAXIMUM ENGINE GIMBAL ANGLE — DEGREES
	PITCH	YAW	ROLL	
MES1	-1.50	-0.12	-1.40	+1.36 (C1 PITCH)
	RATES DAMPED TO 0.3 DEG/SEC OR LESS BY MES1 +4 SECONDS			
MES2	-4.30	-0.40	-3.60	+2.4
	TLM DATA OBSCURED BY NOISE BEFORE DAMPING OF MES TRANSIENT. HOWEVER, DAMPING APPEARED IMMINENT			(C1, C2 PITCH)
MES3	-8.0	+0.3	-4.2	+1.28
	RATES DAMPED TO LESS THAN 0.5 DEG/SEC BY MES3 +7.5 SECONDS			(C1, C2 PITCH)
MES4	-9.3	+1.2	-4.7	+1.6
	RATES DAMPED TO LESS THAN 0.5 DEG/SEC BY MES4 +8 SECONDS			(C1, C2 PITCH)

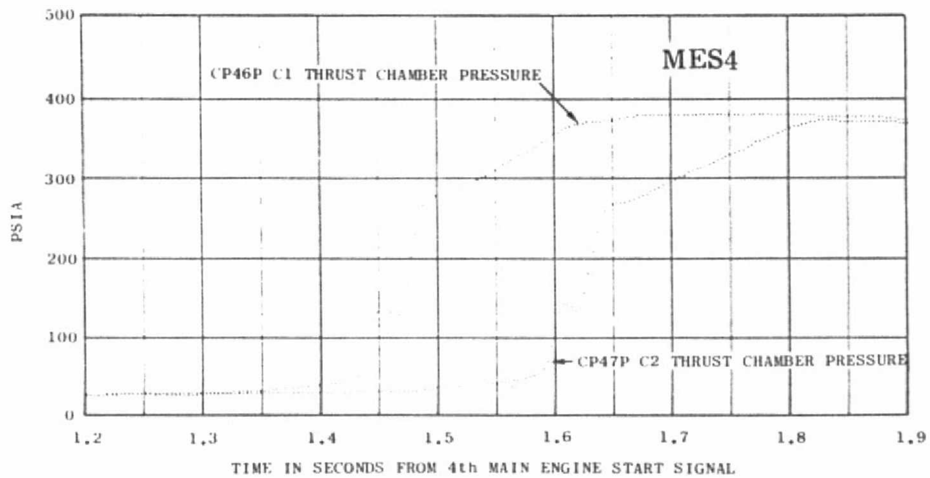
MAIN ENGINE START PERFORMANCE
MES1 AND MES2





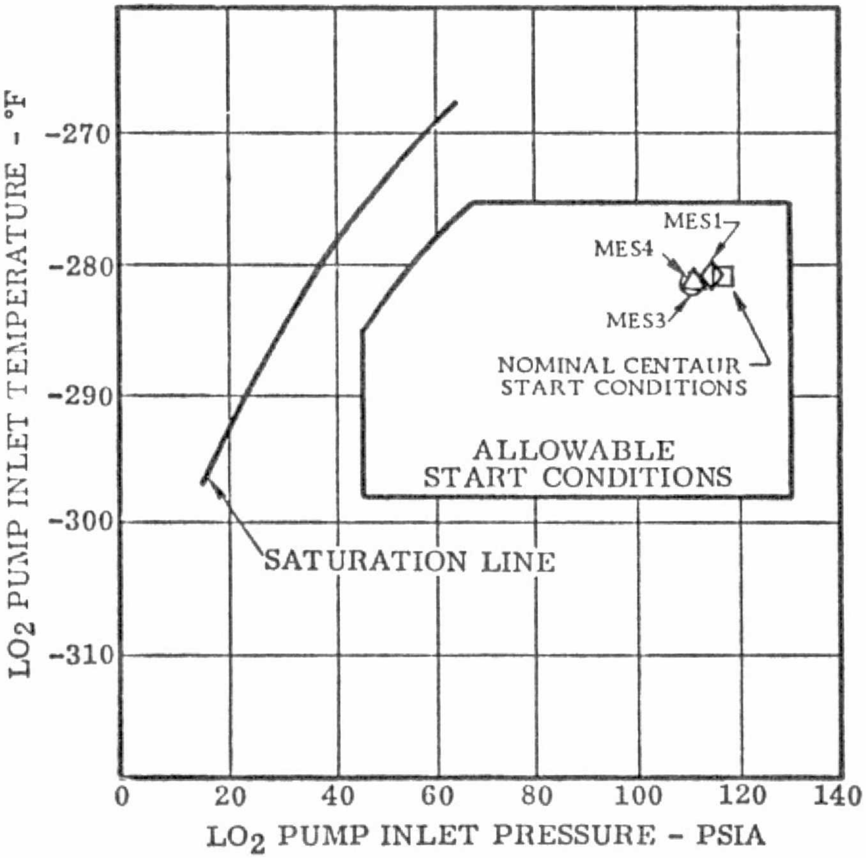
MAIN ENGINE START PERFORMANCE
MES3 AND MES4



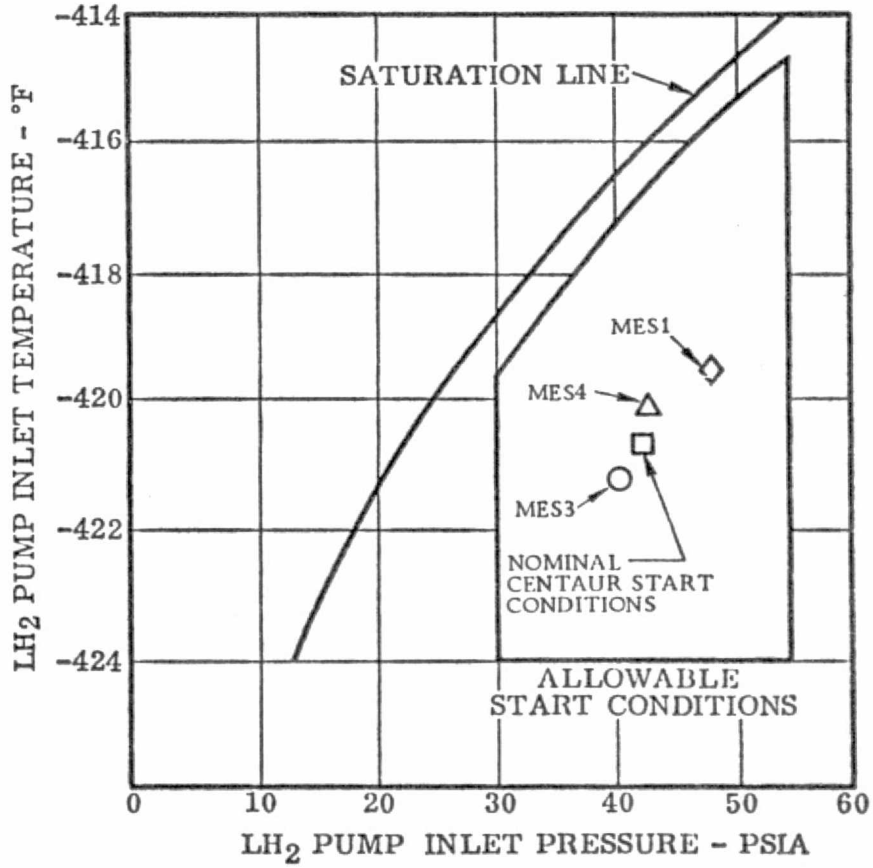


ENGINE INLET CONDITIONS WERE SATISFACTORY FOR ALL BURNS

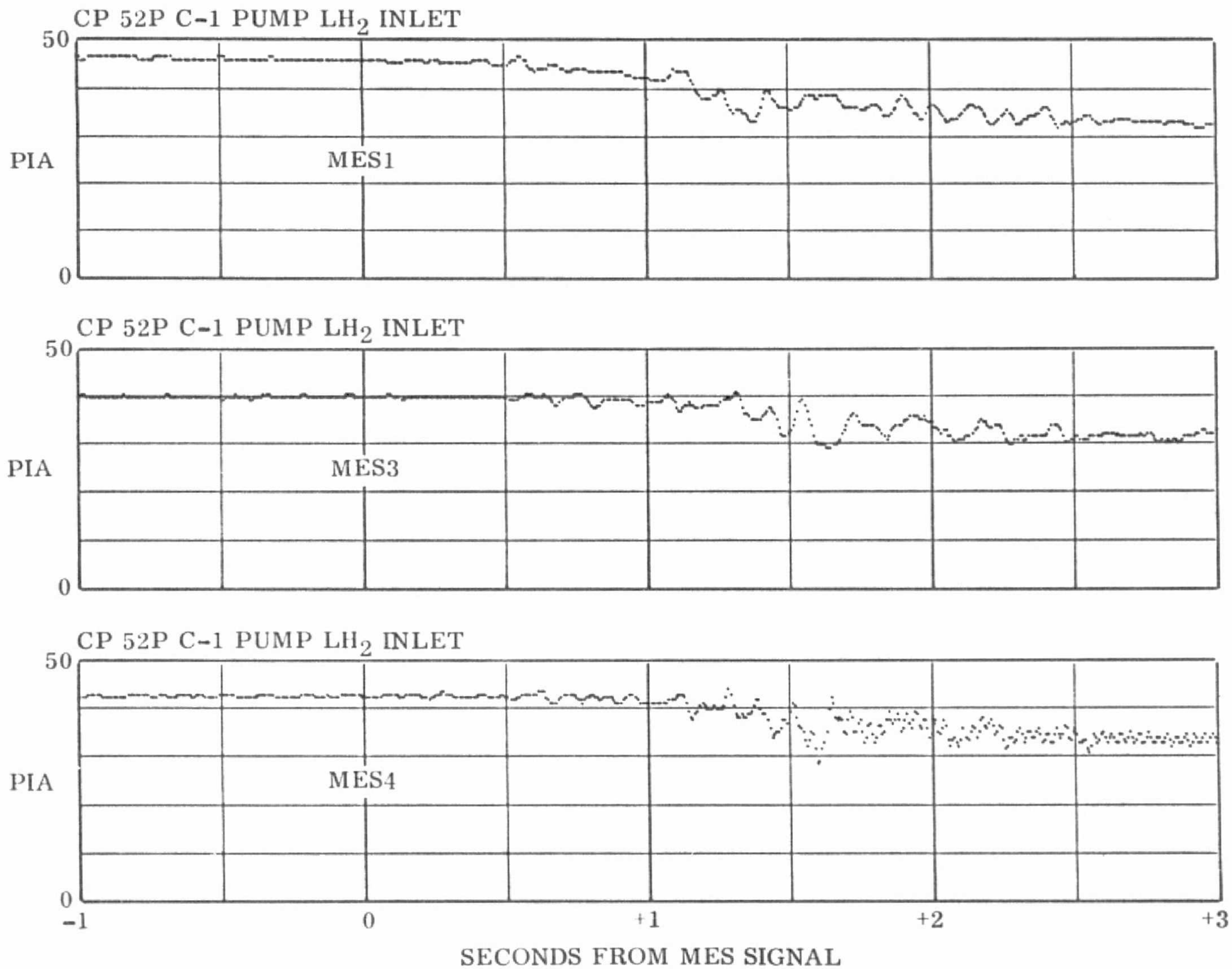
MAIN ENGINE LO_2 PUMPS NPSP CONDITIONS



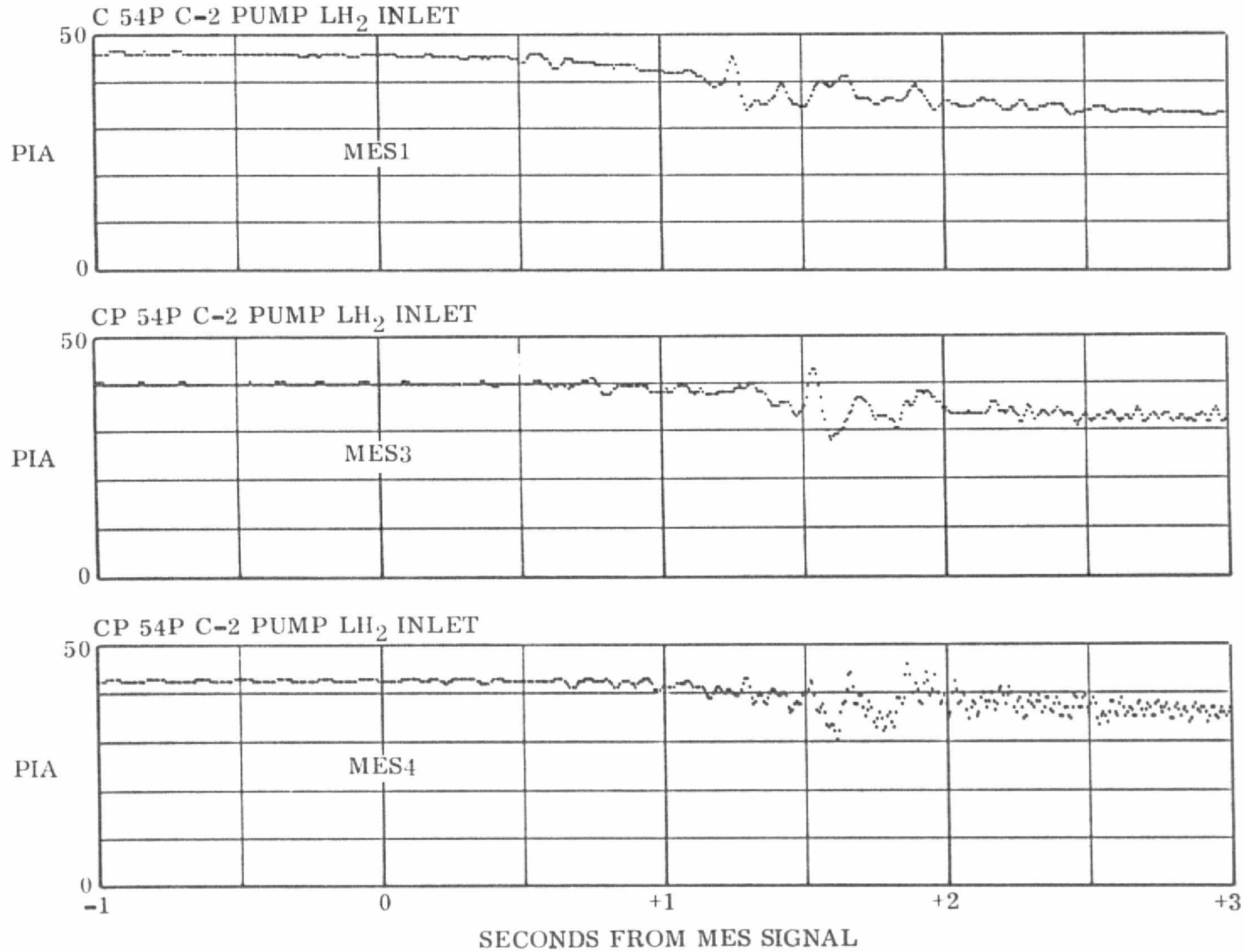
MAIN ENGINE LH_2 PUMPS NPSP CONDITIONS



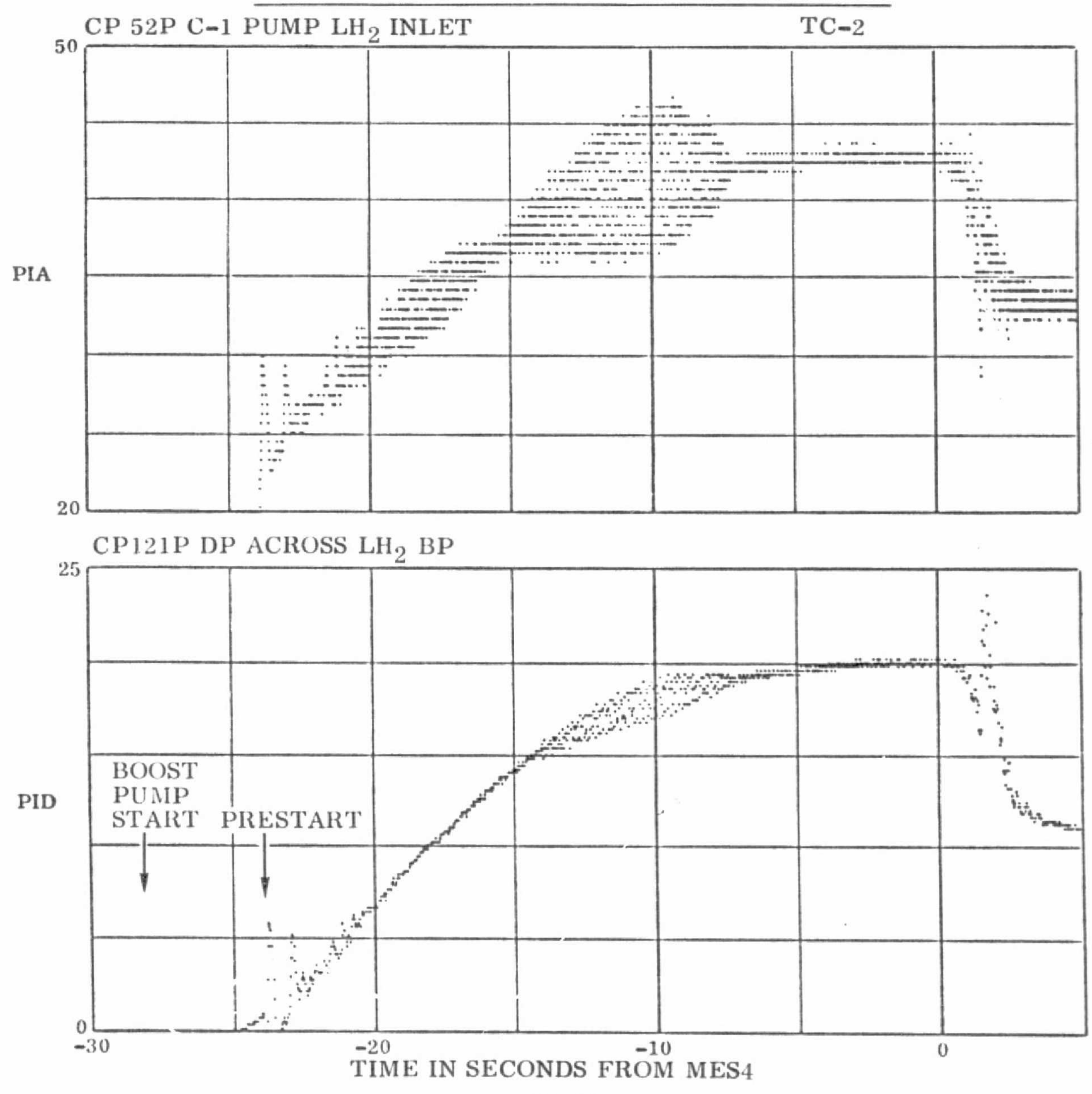
MAIN ENGINE PERFORMANCE – CP 52P C-1 PUMP LH_2 INLET PRESSURE



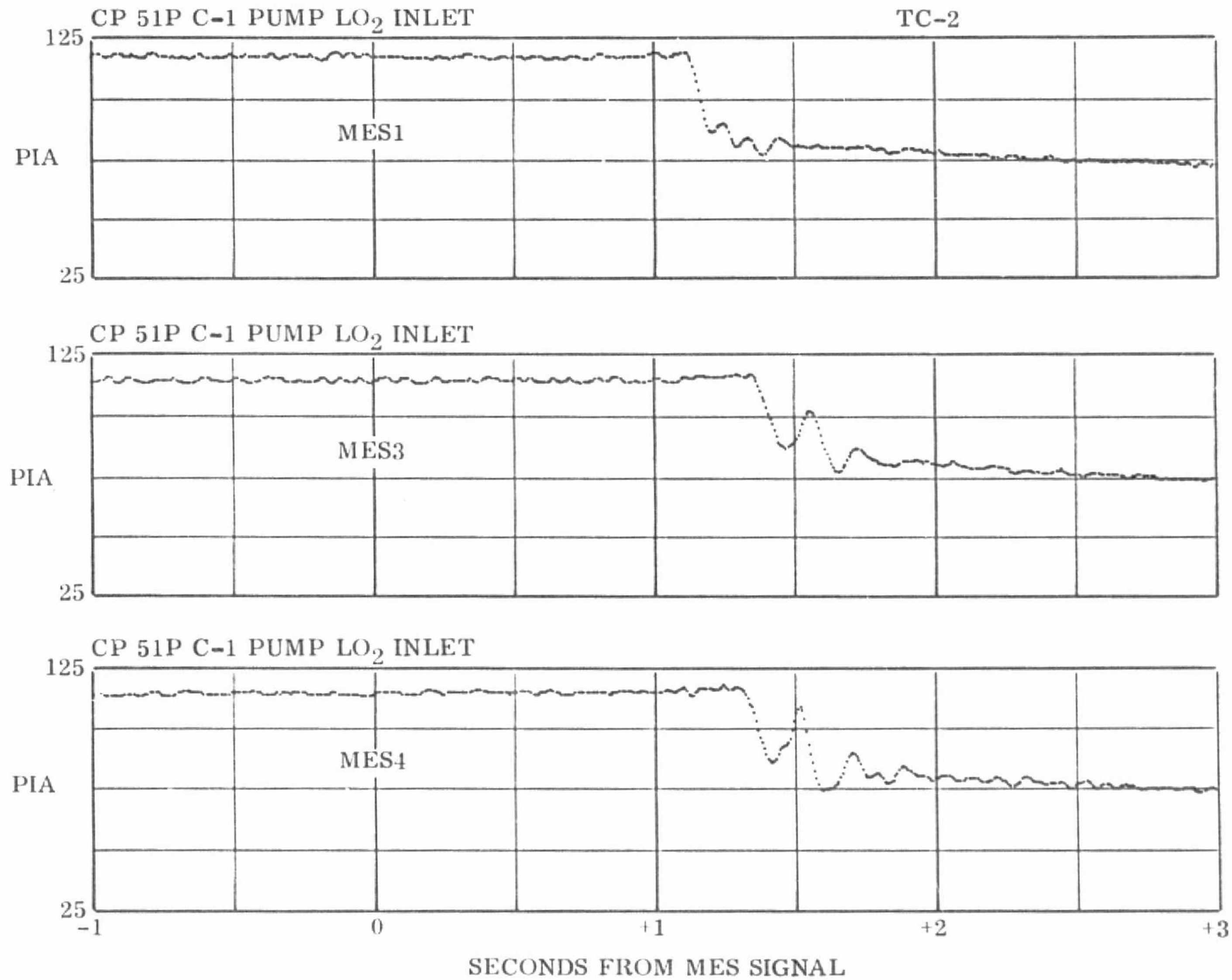
MAIN ENGINE PERFORMANCE–
CP 54P C-2 PUMP LH_2 INLET PRESSURE



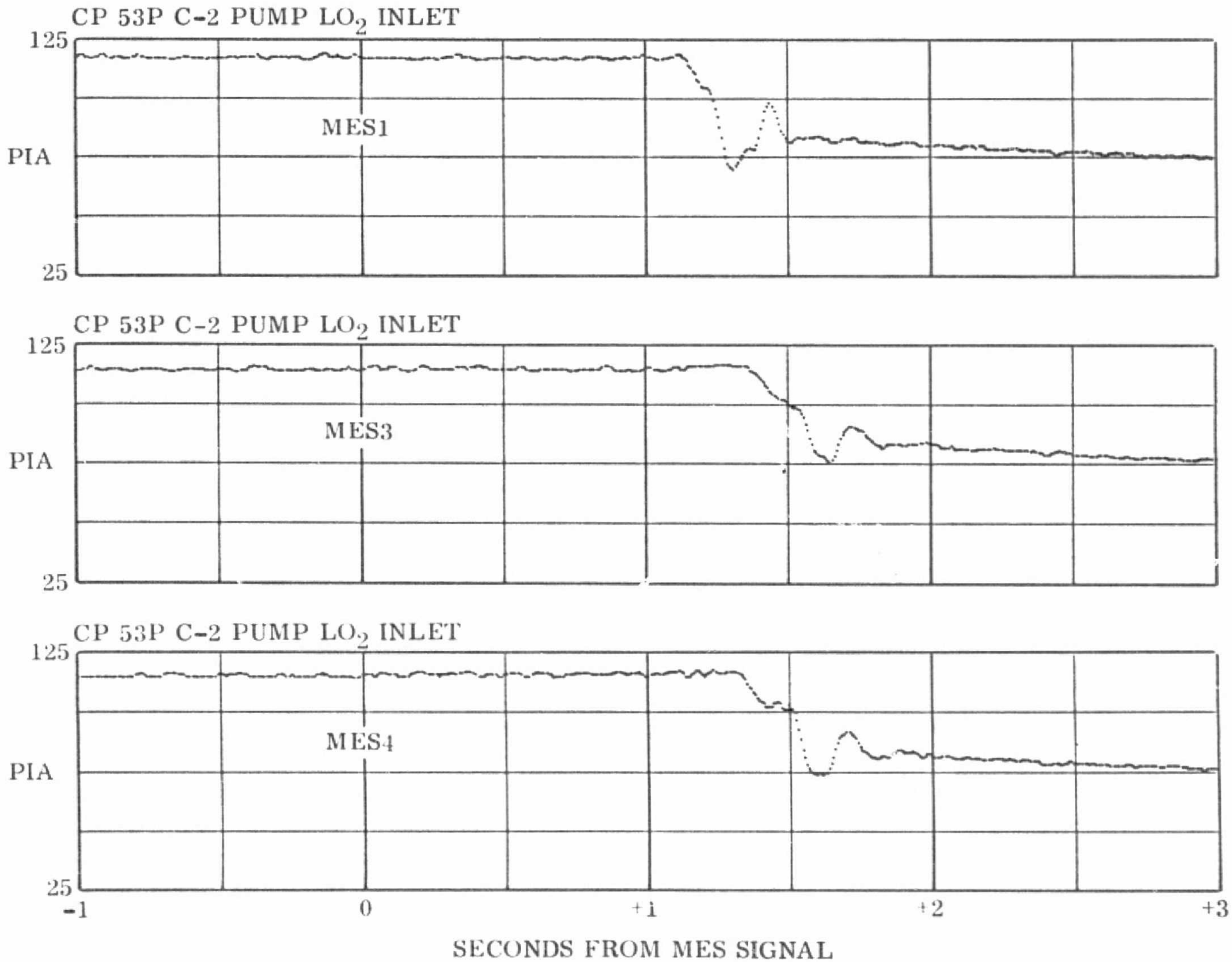
MES4 ENGINE FUEL PUMP INLET PRESSURE OSCILLATIONS



MAIN ENGINE PERFORMANCE- CP 51P C-1 PUMP LO_2 INLET PRESSURE



MAIN ENGINE PERFORMANCE–
CP 53P C-2 PUMP LO_2 INLET PRESSURE



MAIN ENGINE CUT-OFF IMPULSE WAS NEAR NOMINAL

	CUT-OFF IMPULSE — LB-SEC		
	CHAMBER PRESSURE DATA	GUIDANCE DATA	EXPECTED
MECO1	3320	3550 ± 200	3250 ± 930
MECO2	3487	3660 ± 100	3250 ± 930
MECO3	3363	3540 ± 100	3250 ± 930
MECO4	3360	3440 ± 100	3250 ± 930

	CUT-OFF IMPULSE DIFFERENTIAL — LB-SEC
	CHAMBER PRESSURE DATA
MECO1	29
MECO2	4
MECO3	34
MECO4	7
AVERAGE (AC30-35)	
MECO1	131
MECO2	83

	MECO THRUST TRANSIENT DISTURBANCES — MAX VEHICLE RESIDUAL RATE DEG PER SEC		
	PITCH	YAW	ROLL
MECO1	-0.24	-0.10	-0.46
MECO2	+0.02	0	-0.80
MECO3	-0.24	+0.12	-0.44
MECO4	-0.16	+0.34	-0.72

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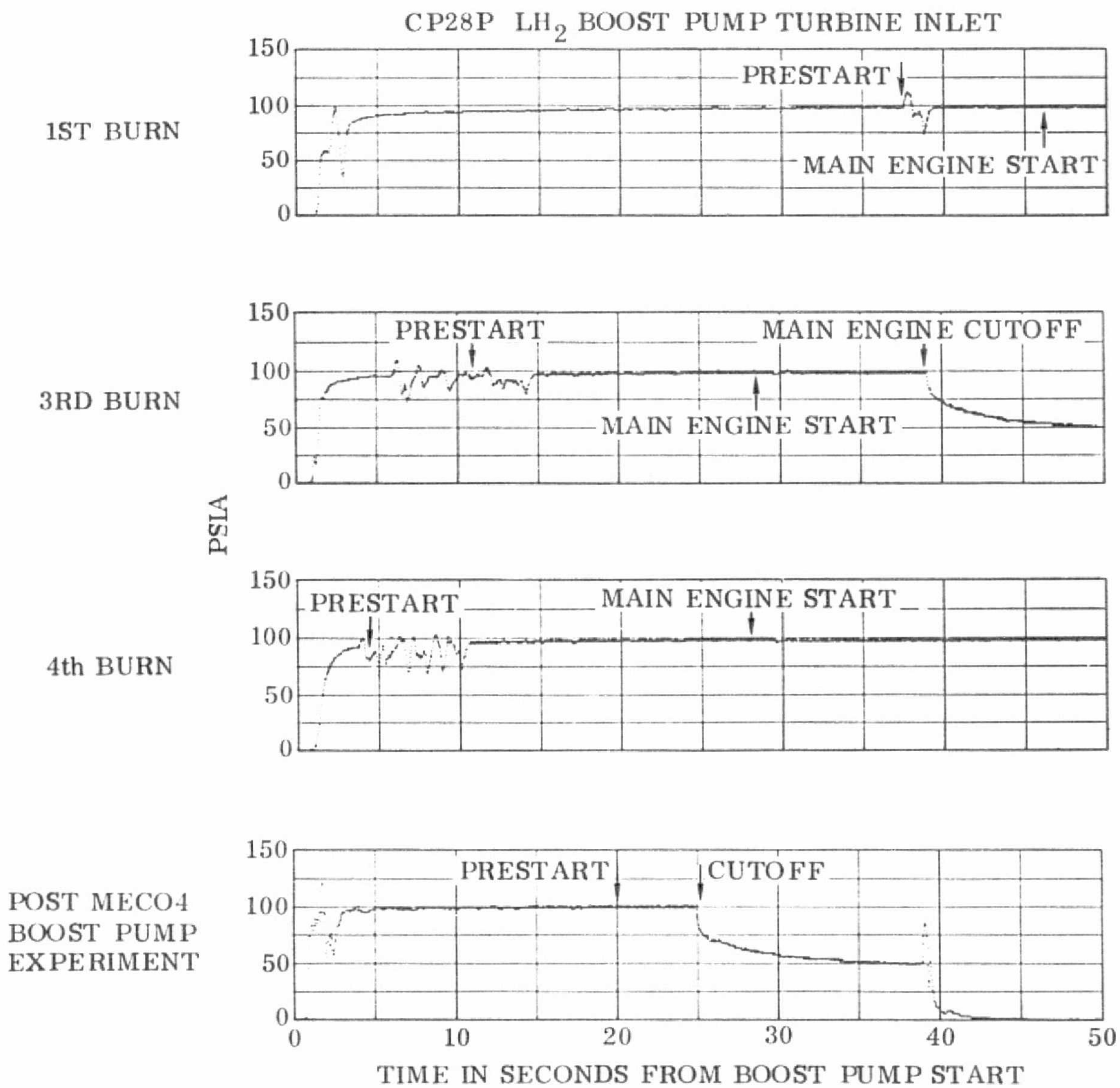
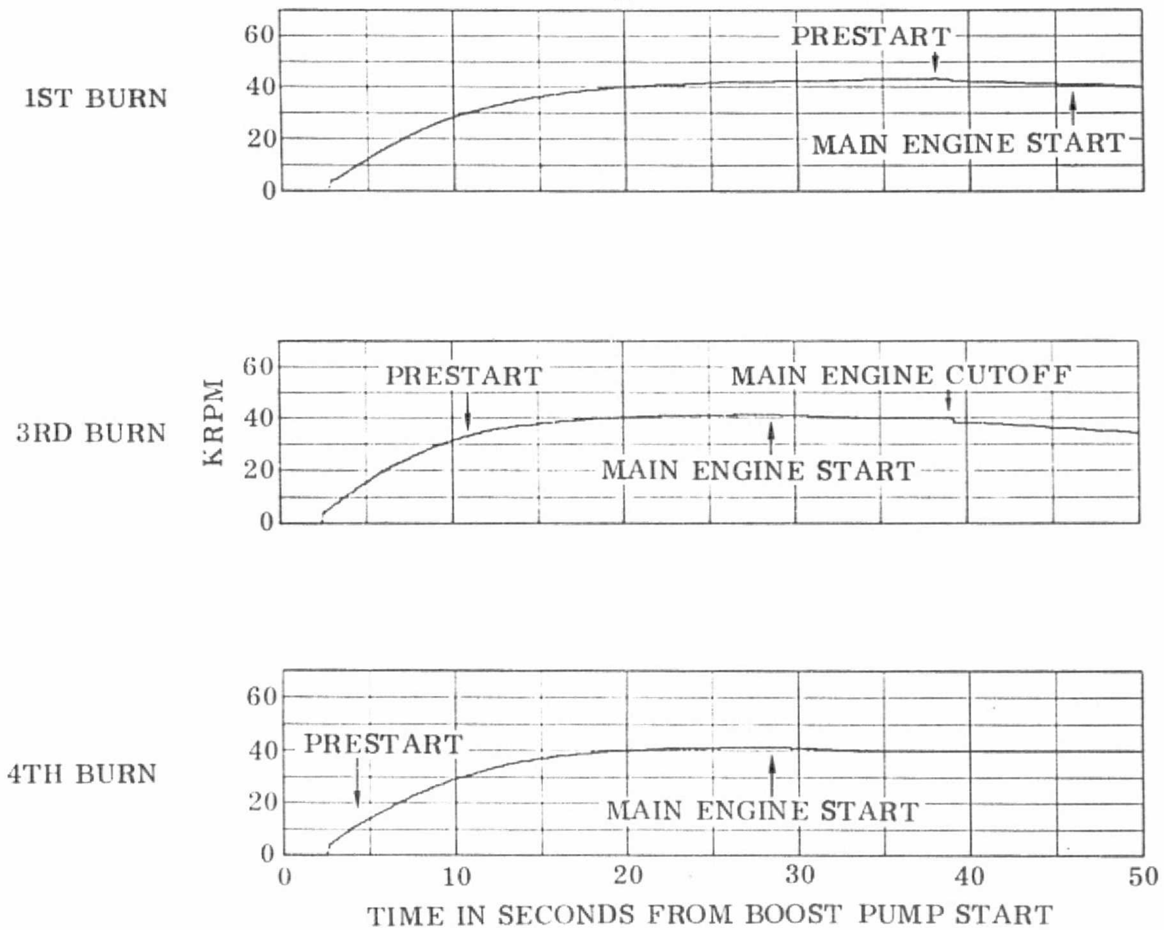
LH_2 BOOST PUMP PERFORMANCE
TURBINE INLET PRESSURE

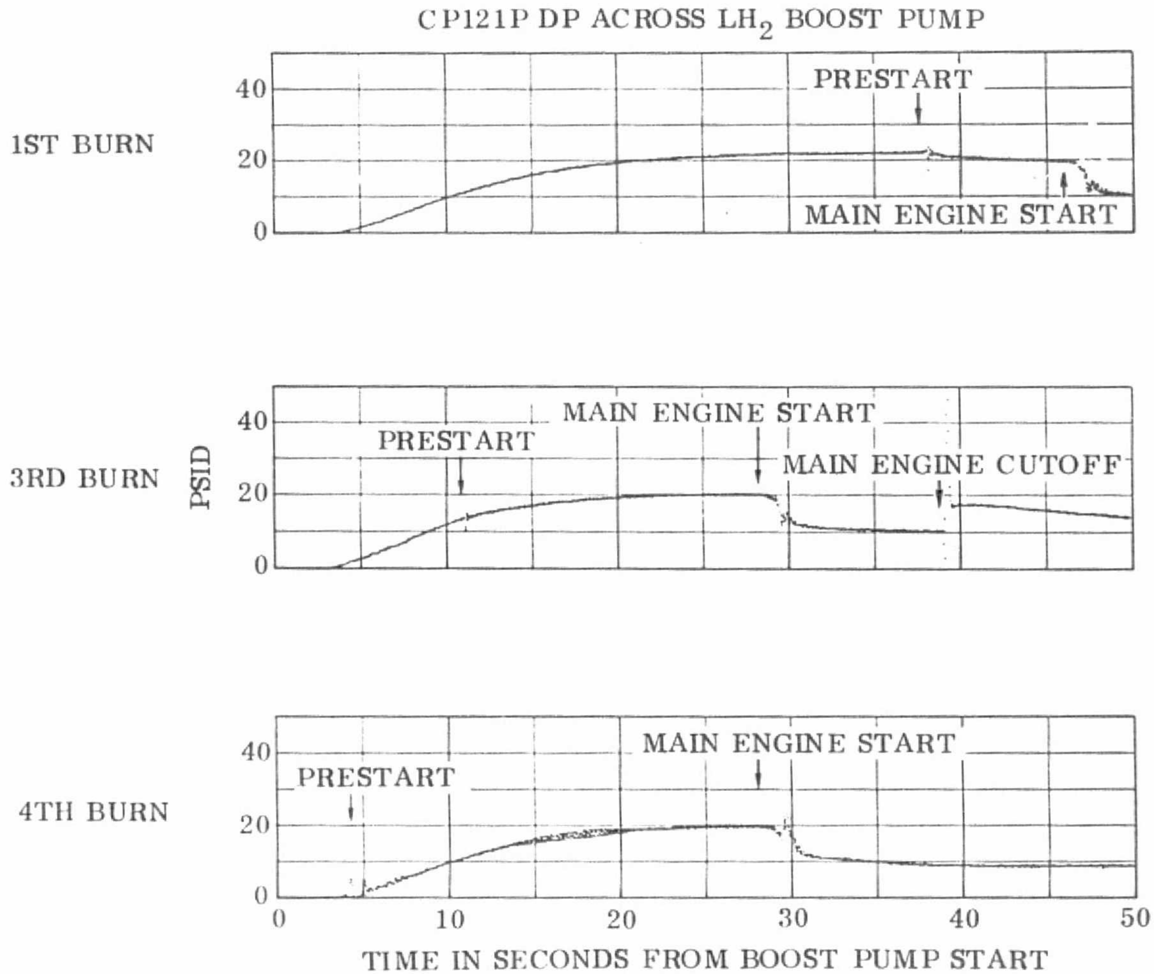


LH_2 BOOST PUMP PERFORMANCE–SPEED

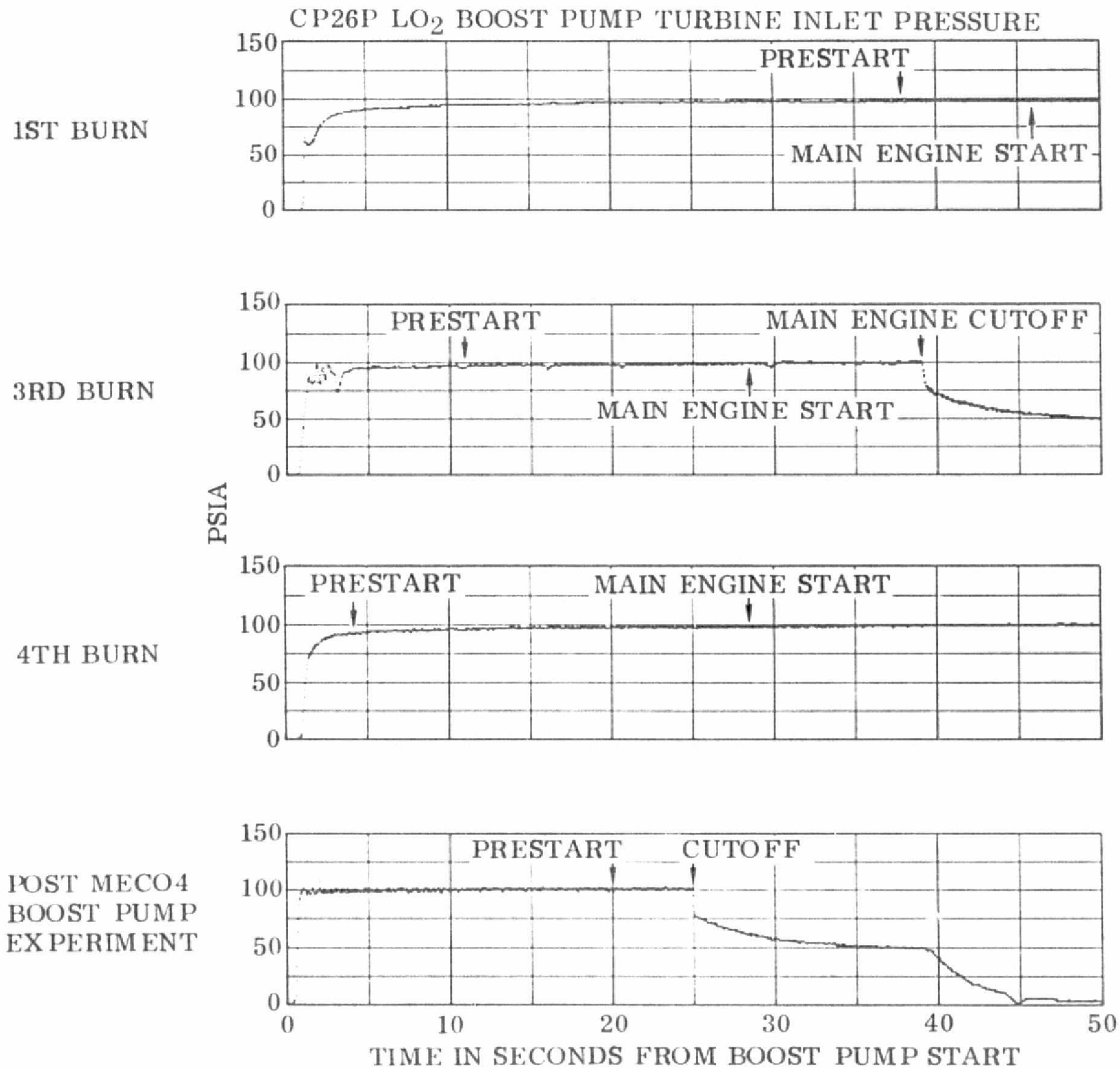
CP16B LH_2 BOOST PUMP SPEED



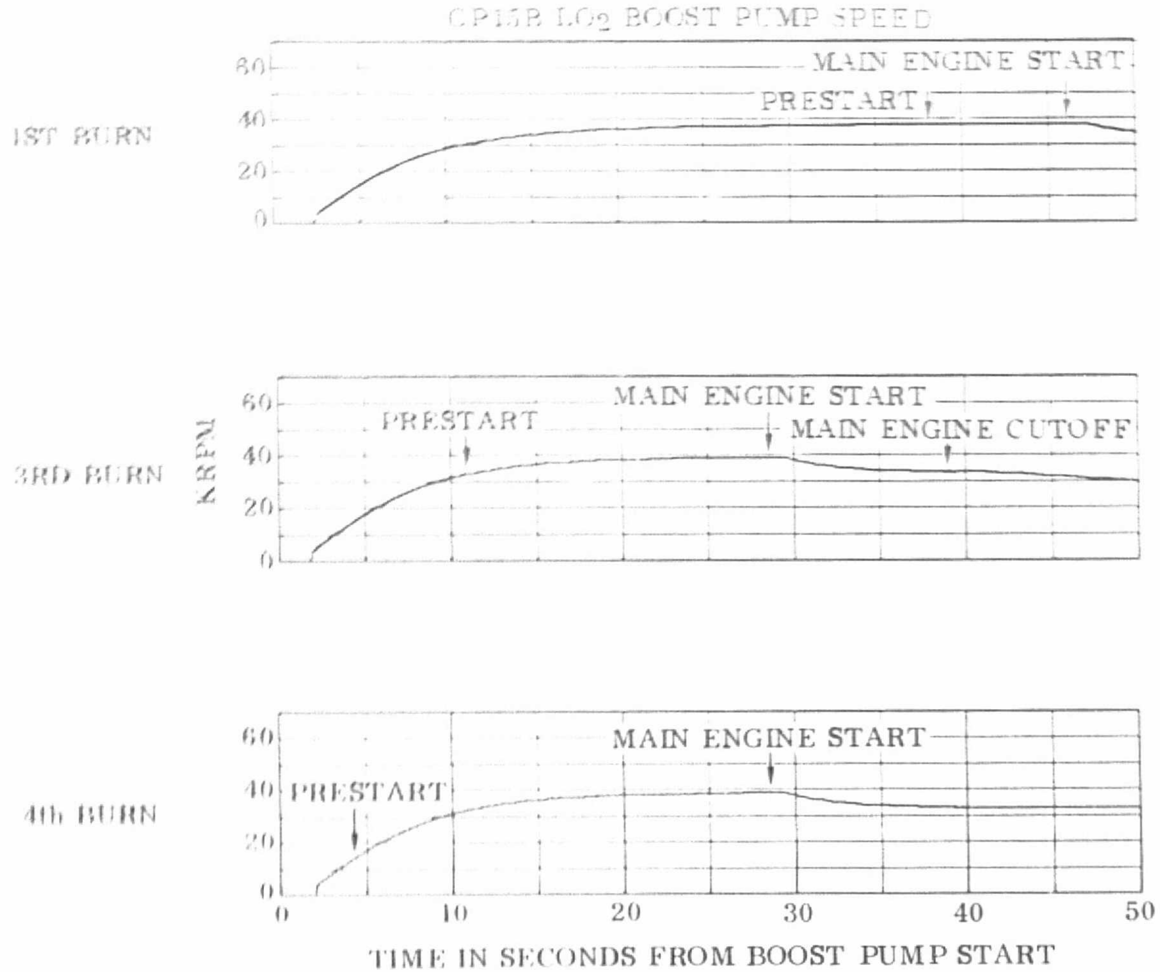
LH_2 BOOST PUMP PERFORMANCE–HEAD RISE



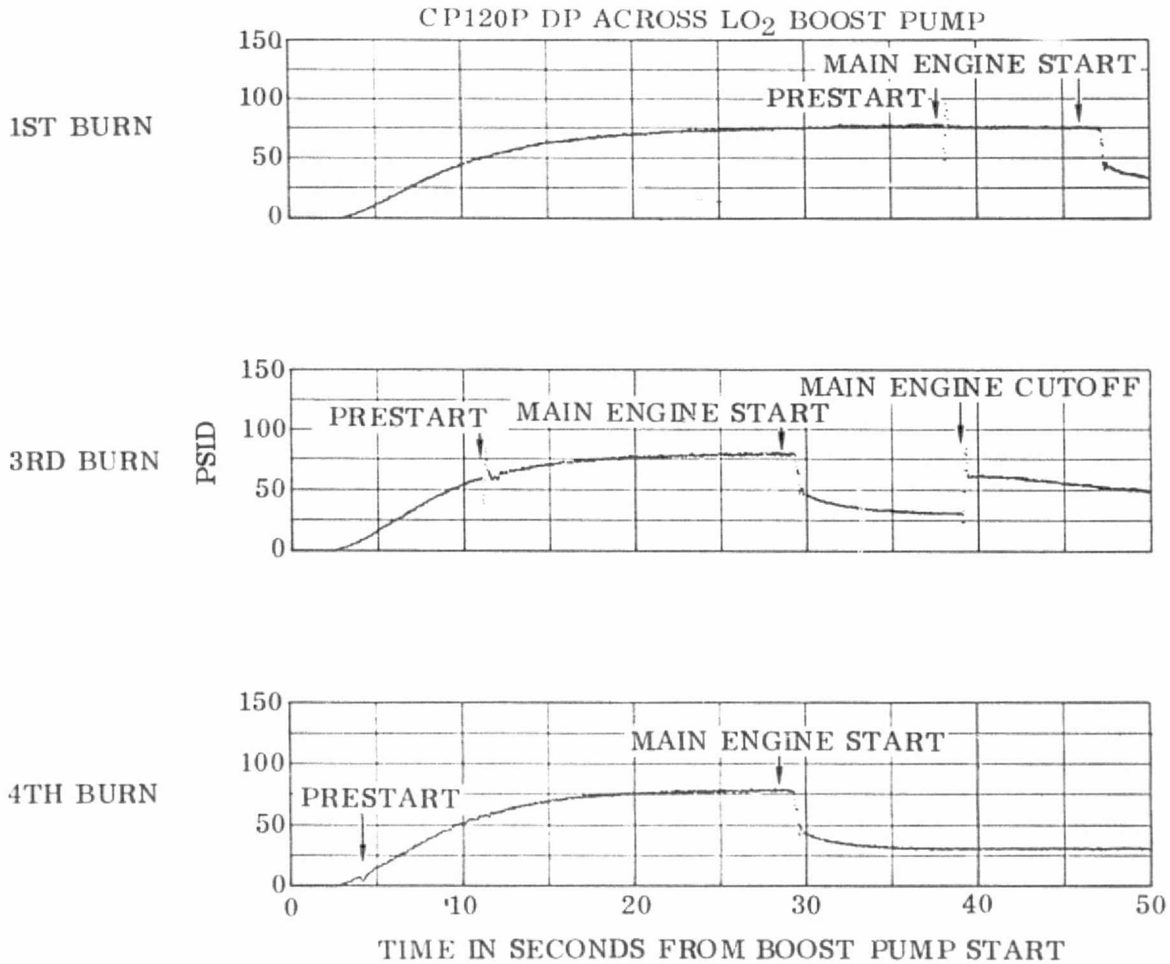
LO_2 BOOST PUMP PERFORMANCE– TURBINE INLET PRESSURE



LO_2 BOOST PUMP PERFORMANCE-SPEED



LO_2 BOOST PUMP PERFORMANCE
HEAD RISE



MECO4 INITIATION BASED ON VEHICLE WEIGHT

- FOURTH BURN TERMINATED BY DCU CALCULATED TOTAL VEHICLE WEIGHT BASED ON SENSED ACCELERATION.
- REQUIRED TO ASSURE ADEQUATE PROPELLANTS FOR POST MECO4 BOOST PUMP EXPERIMENT.
- TECHNIQUE DEMONSTRATED TO BE SATISFACTORY
  - ▲ POST FLIGHT ESTIMATED VEHICLE WEIGHT AT MECO4 OF 6365 LB WAS 165 LB GREATER THAN TARGETED VALUE OF 6200 LB (REF. — GDC REPORT 672-1-75-017)
    - ATTRIBUTED PRIMARILY TO DIFFERENCE BETWEEN NOMINAL THRUST LEVEL USED BY SOFTWARE TO COMPUTE WEIGHT AND ACTUAL THRUST LEVEL CALCULATED FROM POST-FLIGHT ANALYSIS OF ENGINE DATA.
    - PLAN TO USE BIASED WEIGHT CUTOFF LEVELS FOR TC-5.

TC-2 POST HELIOS EXPERIMENT DATA REVIEW

I	INTRODUCTION	HUBER
II	PROPELLANT BEHAVIOR	MERINO
III	HELIUM USAGE	MERINO
IV	PROPELLANT TANK PRESSURIZATION	MERINO
V	PROPELLANT TANK THERMODYNAMICS	MERINO
VI	COMPONENT HEATING & THERMAL CONTROL	CHRISTENSEN
VII	MAIN ENGINE SYSTEM	HUBER
VIII	H_2O_2 CONSUMPTION	HUBER
IX	BOOST PUMP POST-MECO PERFORMANCE	HUBER/MERINO
X	OVERVIEW OF OTHER SYSTEMS	HUBER

H_2O_2 CONSUMPTION SUMMARY — ACTUAL VS. PREDICTED

EVENT	TOTAL H_2O_2 CONSUMED (LB) CALCULATED ACTUAL	PREDICTED*
MECO1	18.2	18.1
MECO2	182.6	181.6
MECO3	238.0	237.4
MECO4	331.0	360.7
START DEPLETION EXPERIMENT	356.0	382.8
AT DEPLETION	476.0	476.0

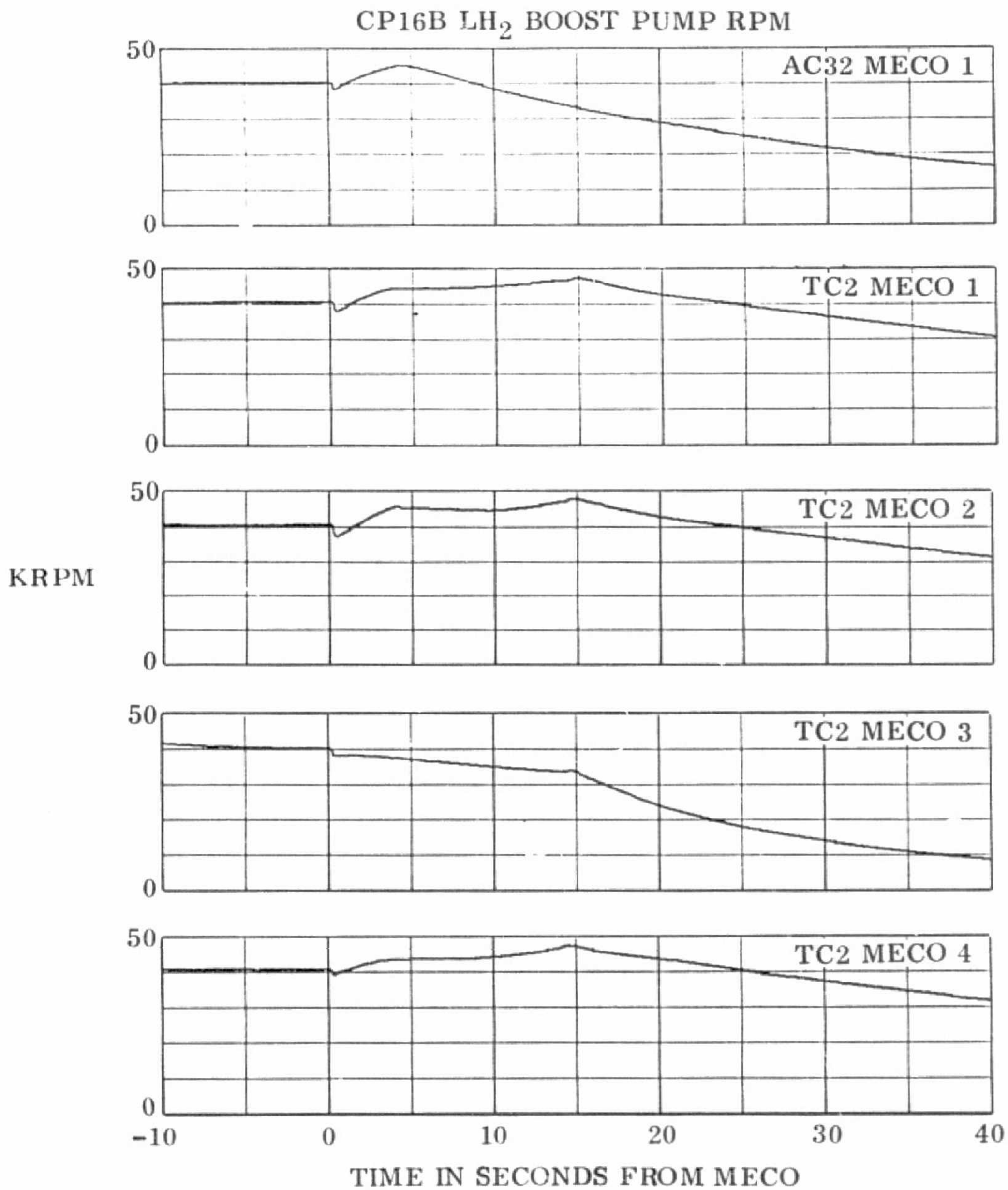
*PREFLIGHT PREDICTION CORRECTED FOR ACTUAL BURN TIMES AND COAST TIMES.

H_2O_2 CONSUMPTION DIFFERENCES ARE ATTRIBUTED TO 3RD COAST P/Y ENGINE USAGES

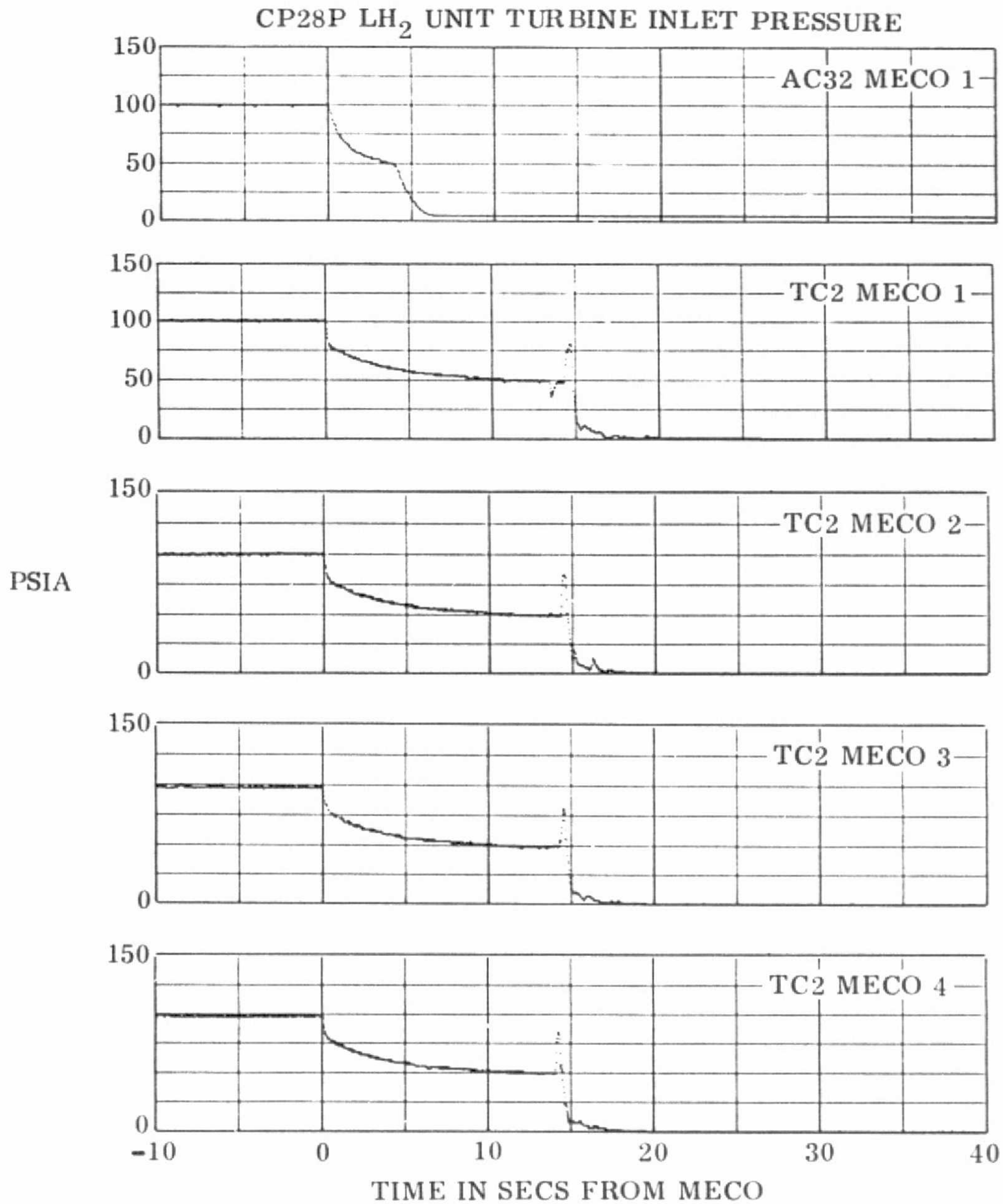
3RD COAST MODE	CONSUMPTION (LB) ACTUAL	CONSUMPTION (LB) PREDICTED
P&Y CONTROL – ZERO-G	6.4	21.6
THERMAL MANEUVERS (6)	9.3	23.6
P/Y WARMING (1)	2.9	2.9
S WARMINGS (2)	0.0	0.2
PROGRAMMED VENT (1)		
2S ON (180 SEC)	1.3	2.2
4S ON (40 SEC)	0.4	0.4
PRE-MES4 SETTLING:		
2S ON (300 SEC)	2.1	3.2
4S ON (119.4 SEC)	2.2	1.0
TOTAL	(24.6)	(55.1)

TC-2 POST HELIOS EXPERIMENT DATA REVIEW

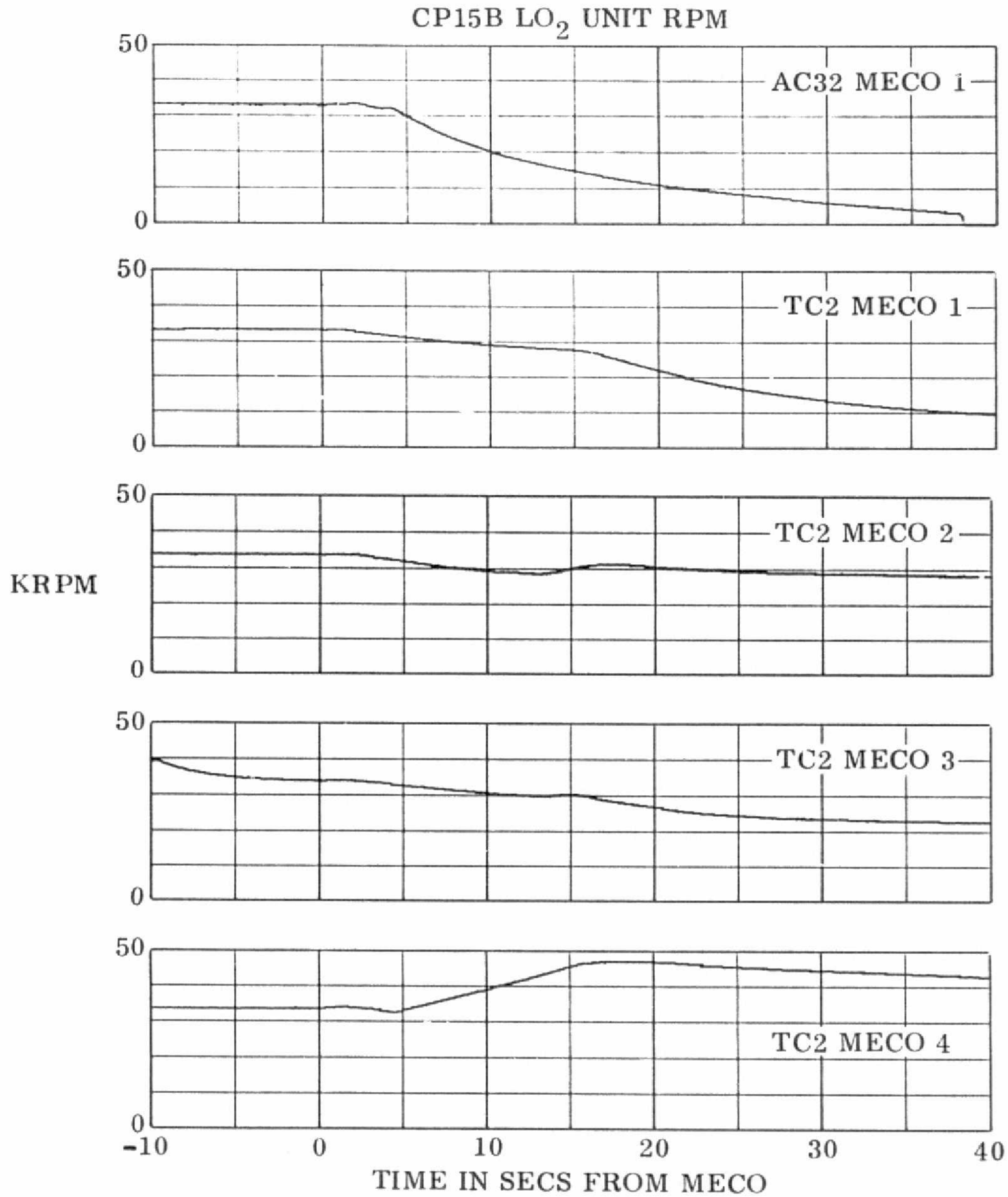
POST-MECO LH_2 BOOST PUMP OVERSPEED



POST-MECO LH_2 BOOST PUMP TURBINE INLET PRESSURE

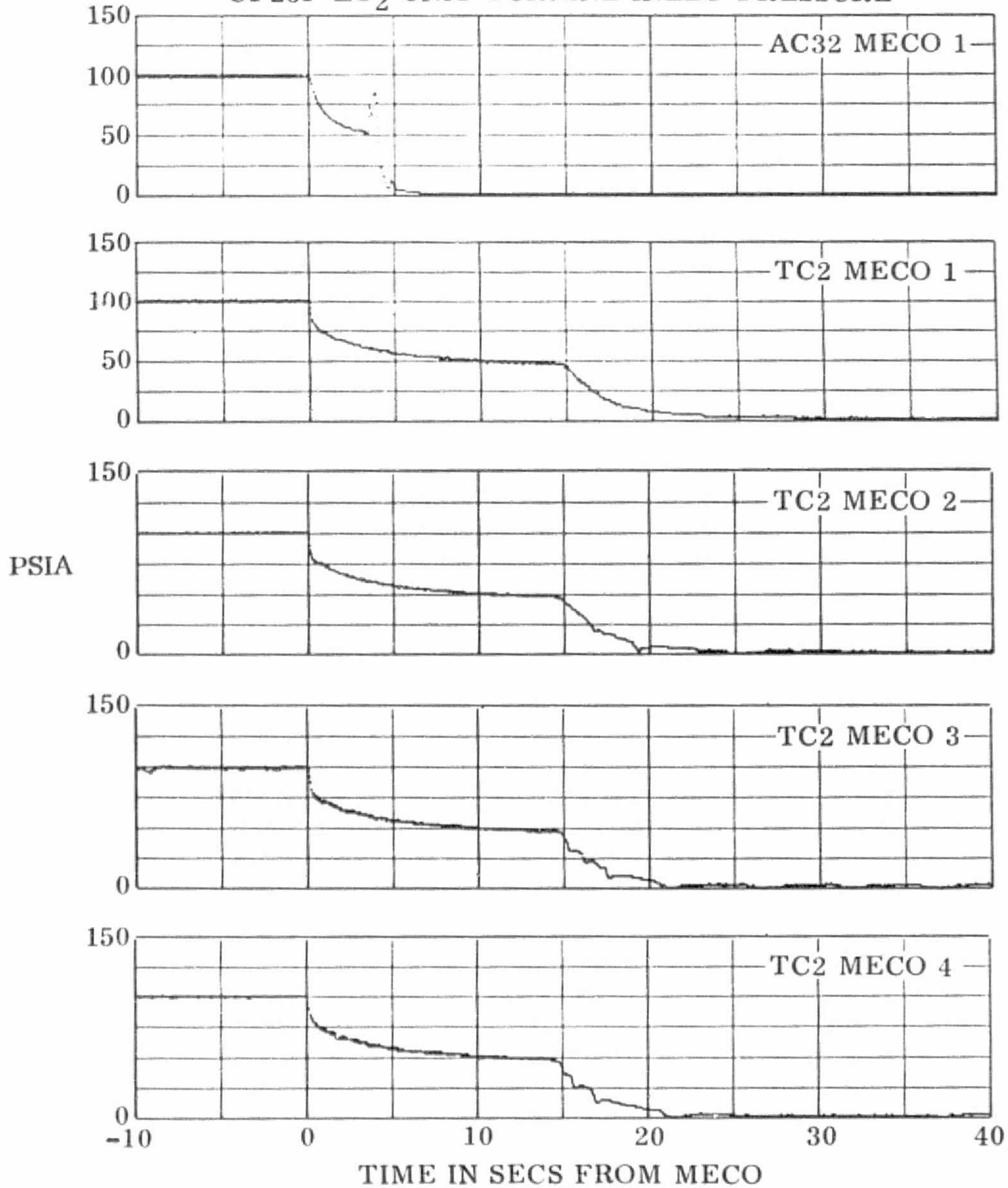


POST-MECO LO2 BOOST PUMP OVERSPEED



POST-MECO LO_2 BOOST PUMP TURBINE INLET PRESSURE

CP26P LO_2 UNIT TURBINE INLET PRESSURE



MAXIMUM BOOST PUMP POST-MECO SPEEDS – ACTUAL VS. EXPECTED

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- OBSERVED FLIGHT PEAK RPM

		LO_2 UNIT	LH_2 UNIT
AC-32 POST MECO	1	NO PEAK	45,000
TC-2	1	NO PEAK	47,600
	2	NO PEAK	47,000
	3	NO PEAK	NO PEAK
	4	47,000	47,000
TC-2	4 BOOST PUMP EXPERIMENT	61,000	55,300
TC-4	1	NO PEAK	46,570
TC-4	2	60,300	63,000
TC-3	1	NO PEAK	48,920
TC-3	2	56,170	53,880
AC-36	1	35,900	52,800
AC-36 POST MECO	2	57,760	58,520

- REVIEW OF MAX ALLOWABLE VERSUS MAX EXPECTED TURBINE SPEED WITH REDUNDANT H_2O_2 SUPPLY SYSTEM (REF. GDC REPORT ES-S-43)

	SPEED - RPM
▲ MAX ALLOWABLE TURBINE SPEED	
– UNIT-TO-UNIT TURBINE PROOF TEST	65,650
– TURBINE BURST TESTS - 4 SAMPLES, FAILURE OCCURRING AT	77,000
	78,000
	83,600
	>85,330

	LO_2 UNIT	LH_2 UNIT
▲ MAX PREDICTED TURBINE SPEED		
– ANALYTICAL METHOD 1	60,000	66,000
– ANALYTICAL METHOD 2	58,000	60,000
– BASED ON LeRC TEST RESULTS	65,000	

▲ CONCLUSION — MAX SPEED TURBINE IS WITHIN RANGE CONSIDERED SAFE AND ACCEPTABLE

POST-MECO4 BOOST PUMP EXPERIMENT

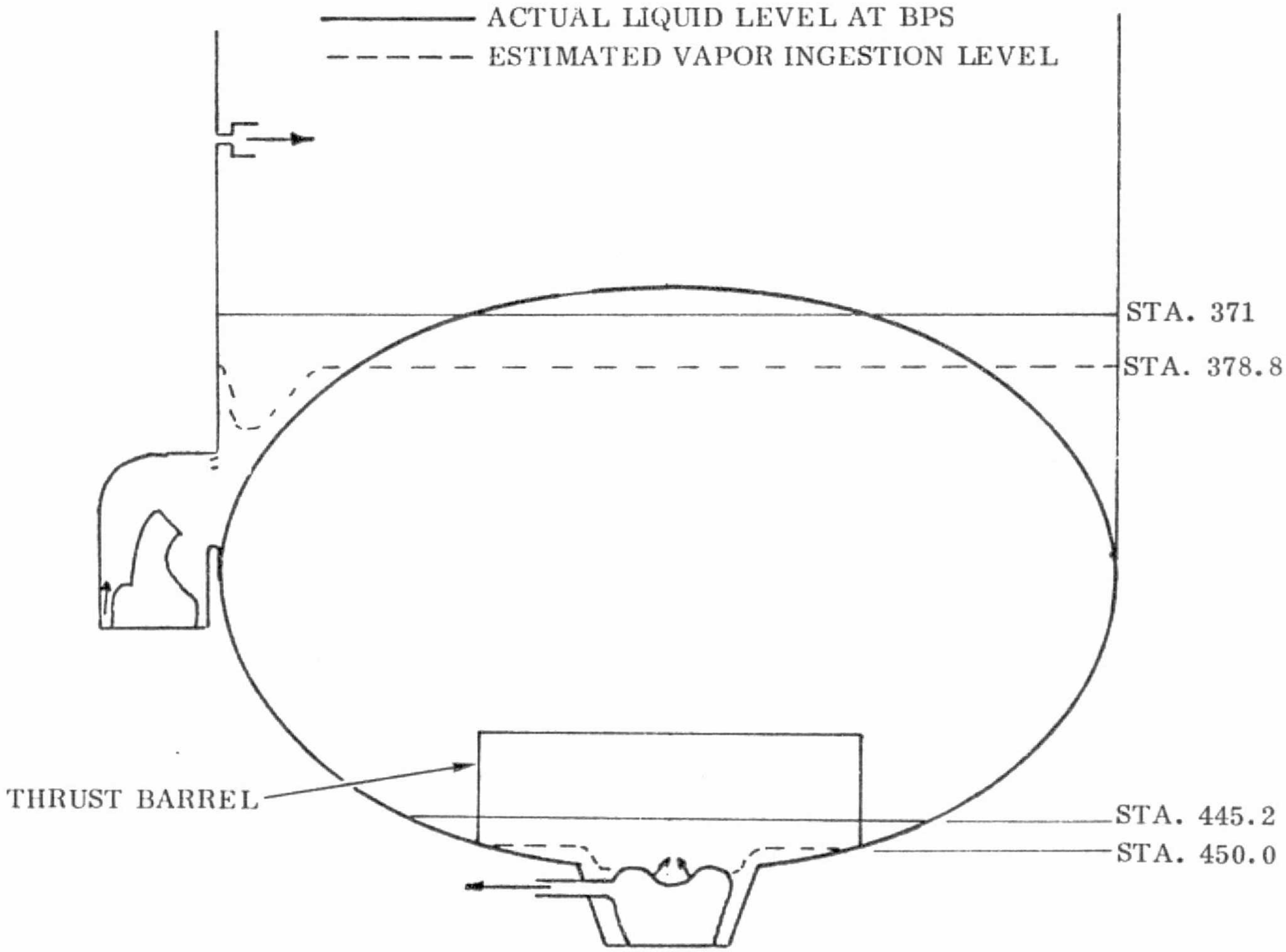
SEQUENCE OF EVENTS

- START 4S SETTLED THRUST AT MECO4 +200 SECONDS.
- START BOOST PUMPS AT MECO4 +280 SECONDS.
- OPEN PRESTART VALVES AT MECO4 +300 SECONDS.
- STOP BOOST PUMPS AT MECO4 +305 SECONDS.
- END 4S SETTLED THRUST AT MECO4 +306 SECONDS.

PROPELLANT TANK CONDITIONS AT BOOST PUMP START

- LH_2 IS SETTLED. LO_2 IS PARTIALLY SETTLED.
- LIQUID RESIDUALS 302 LB LH_2 AND 790 LB LO_2.
- VAPOR INGESTION SHOULD NOT OCCUR DURING EXPERIMENT.
- LH_2 IN SUMP IS SATURATED AT TANK PRESSURE
  LH_2 BULK IS SATURATED AT TANK PRESSURE.
- LO_2 IN SUMP IS SATURATED AT TANK PRESSURE
  LO_2 BULK IS SUBCOOLED BY 2.1 PSID.
- AN UNKNOWN QUANTITY OF VAPOR EXISTS IN THE SUMPS AND BOOST PUMPS AS A RESULT OF BOILING AT MECO4.

PROPELLANT CONDITION AT START OF BOOST PUMP EXPERIMENT



LH_2 BOOST PUMP PERFORMANCE

- NO TANK PRESSURIZATION WAS PROVIDED.
- PERFORMANCE APPEARED NORMAL UNTIL BPS +15 SECONDS, AT WHICH TIME CAVITATION OCCURRED.
- CAVITATION WAS REFLECTED IN BOOST PUMP PERFORMANCE BY EXHIBITING A LOSS OF HEAD RISE AT THIS TIME.
- A SUDDEN DROP IN HEAD PRESSURE AND A CORRESPONDING SUDDEN INCREASE IN PUMP SPEED OCCURRED JUST BEFORE PRESTART.
- THE BOOST PUMP RECOVERED SHORTLY AFTER PRESTART FLOW WAS INITIATED.

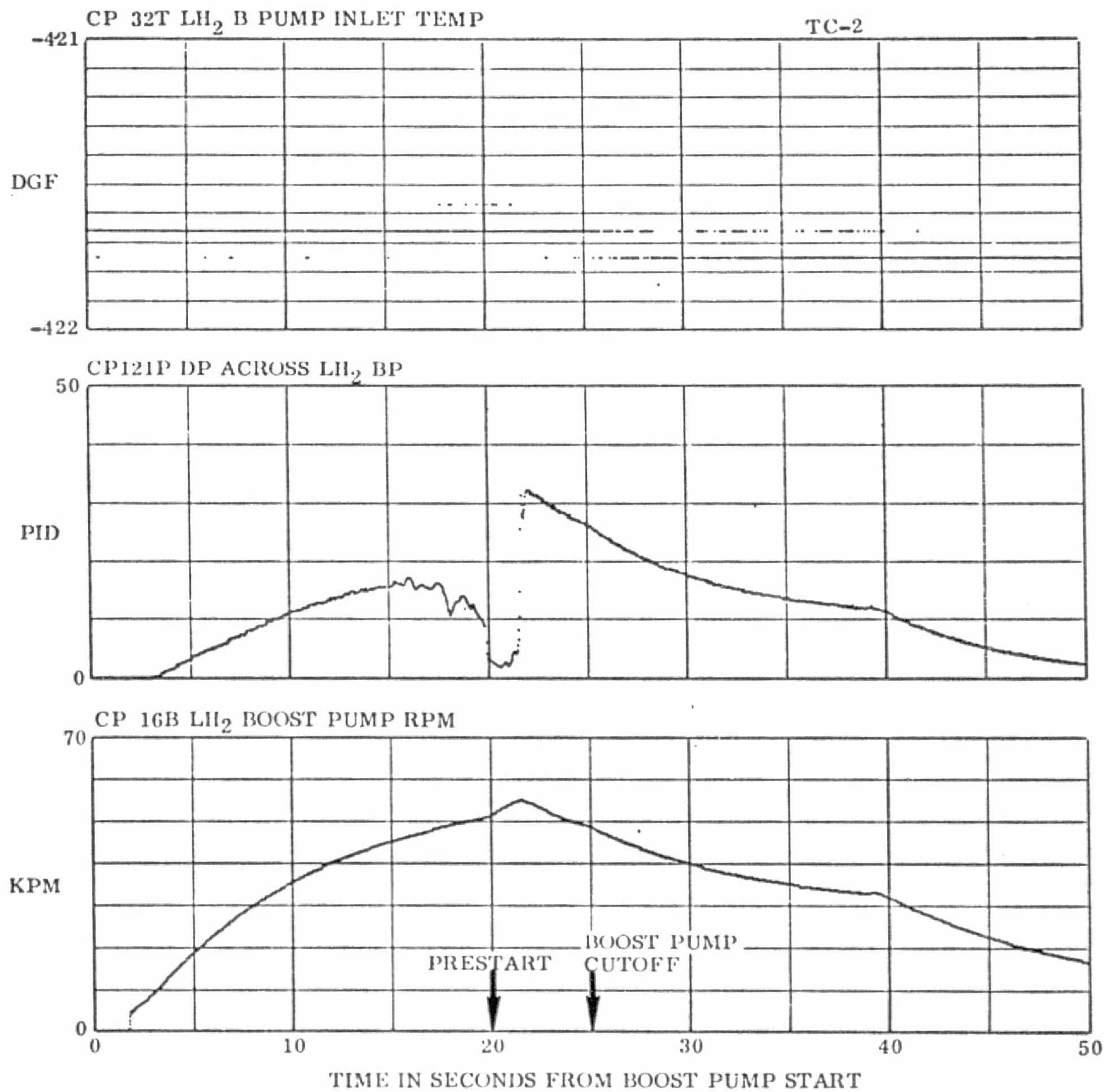
THE FOLLOWING EXPLANATION IS GIVEN FOR THE OBSERVED BOOST PUMP OPERATION

- DURING BOOST PUMP OPERATION BEARING COOLANT HYDROGEN FLOWED INTO THE SUMP AS A TWO PHASE MIXTURE.
- DUE TO THE LOW-G CONDITION (0.003 G'S) VAPOR DID NOT RISE FROM THE SUMP AND BEGAN TO ACCUMULATE.
- CAVITATION OCCURRED AT BPS +15 SECONDS AS A RESULT OF ACCUMULATED VAPOR SPILLING INTO BOOST PUMP INLET DUCT.
- CALCULATED VAPOR ACCUMULATION BY BPS +15 SECONDS IS 0.93 FT^3. MAXIMUM VOLUME BELOW INLET DUCT IS 0.83 FT^3.

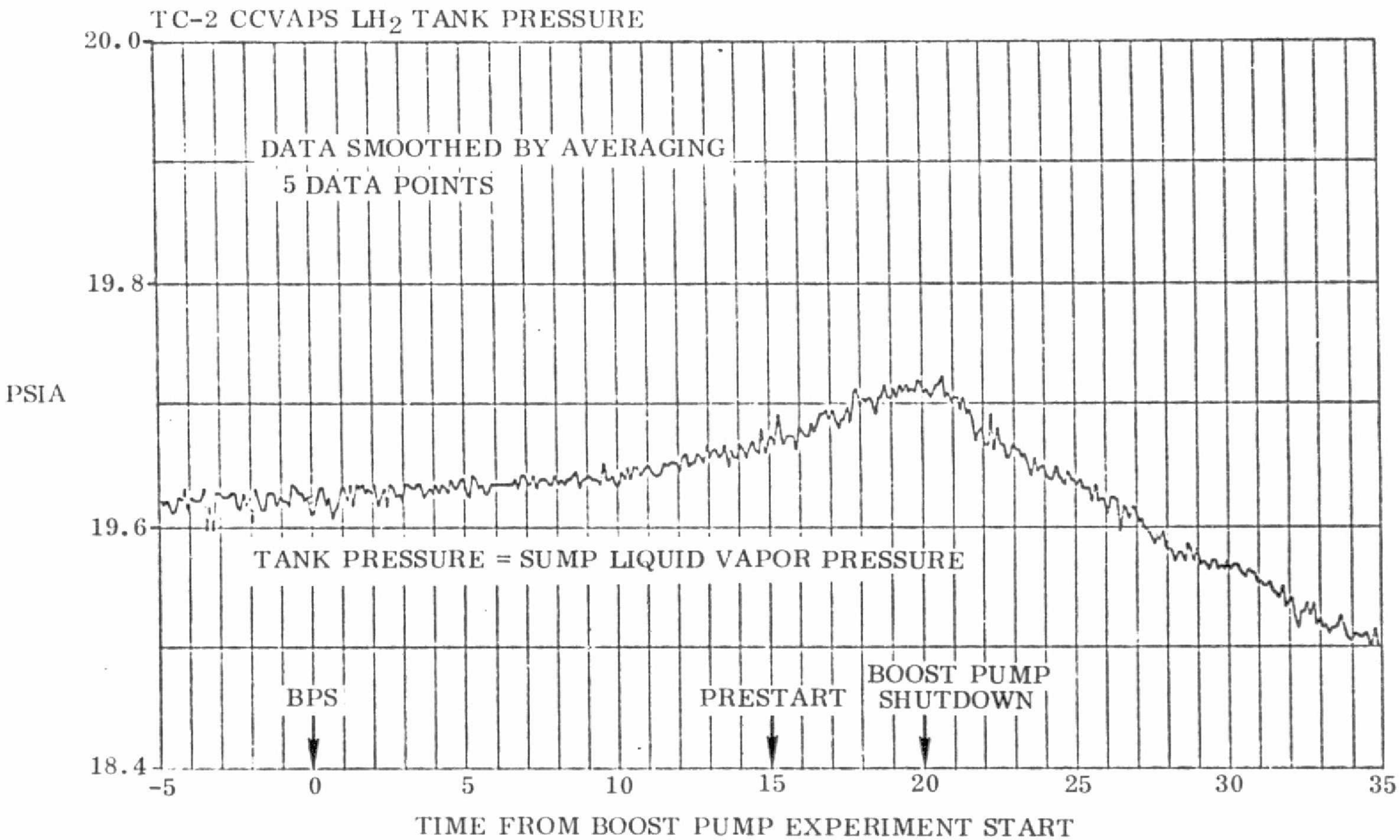
CONCLUSIONS

- BOOST PUMP PERFORMANCE WOULD HAVE BEEN NORMAL THROUGH MES HAD PRESTART OCCURRED AT BPS +11 SECONDS, OR EARLIER, AS WITH THE PREVIOUS FLIGHT EXPERIENCE.
- FOR FUTURE MISSIONS PRESTART MUST OCCUR NO LATER THAN BPS +15 SECONDS IN ORDER TO AVOID CAVITATION.

BOOST PUMP EXPERIMENT – LH_2 UNIT



LH2 TANK PRESSURE DURING BOOST PUMP EXPERIMENT



LO_2 BOOST PUMP PERFORMANCE (MECO4 TO PROPELLANT SETTLING)

- LIQUID WITHIN THE THRUST BARREL BECAME UNSETTLED AFTER MECO4 DUE TO THE MOMENTUM OF THE VOLUTE FLOW INTO THE TANK.
  - VOLUTE FLOWRATE = 21.5 GPM = 3.3 LB/SEC.
  - EXIT AREA = THREE 1/4 INCH DIA. HOLES.
  - EXIT VELOCITY = 47.7 FT/SEC (PURE LIQUID).
- AT MECO4 +4 SECONDS PUMP CAVITATION OCCURRED. CAVIATION WAS CAUSED BY BOILING AT MECO4 AND A TWO-PHASE FLUID CONDITION CREATED BY THE VOLUTE FLOW DURING PUMP SPINDOWN.
  - 490 LB LO_2 CONTAINED WITHIN THRUST BARREL (67% VAPOR BY VOLUME CONTAINED WITHIN THRUST BARREL.)
  - VOLUTE FLOW MOMENTUM DURING 4 SECONDS OF SPINDOWN = 630 LB-$\frac{FT}{SEC}$.
  - FLUID AGITATION CREATES TWO PHASE FLUID (67% BY VOLUME) MOTION OF 1.29 FT/SEC.
- BY INITIATION OF PROPELLANT SETTLING (MECO4 +200) FLUID MOTION HAS DECAYED AND LIQUID COLLECTS IN THE SUMP.
- LIQUID PUMPING BEGAN AT MECO4 +203, AS EVIDENCED BY A HEAD RISE OF 27 PSID (MAX). CAVITATION OCCURRED 8 SECONDS LATER.
  - IT IS BELIEVED THAT CAVITATION WAS CAUSED BY THE UNSETTLING INFLUENCE OF THE VOLUTE FLOW.
  - THE VOLUTE FLOW MOMENTUM WAS ABOUT 600 LB-$\frac{FT}{SEC}$ DURING THE 8 SECOND PUMPING PERIOD.

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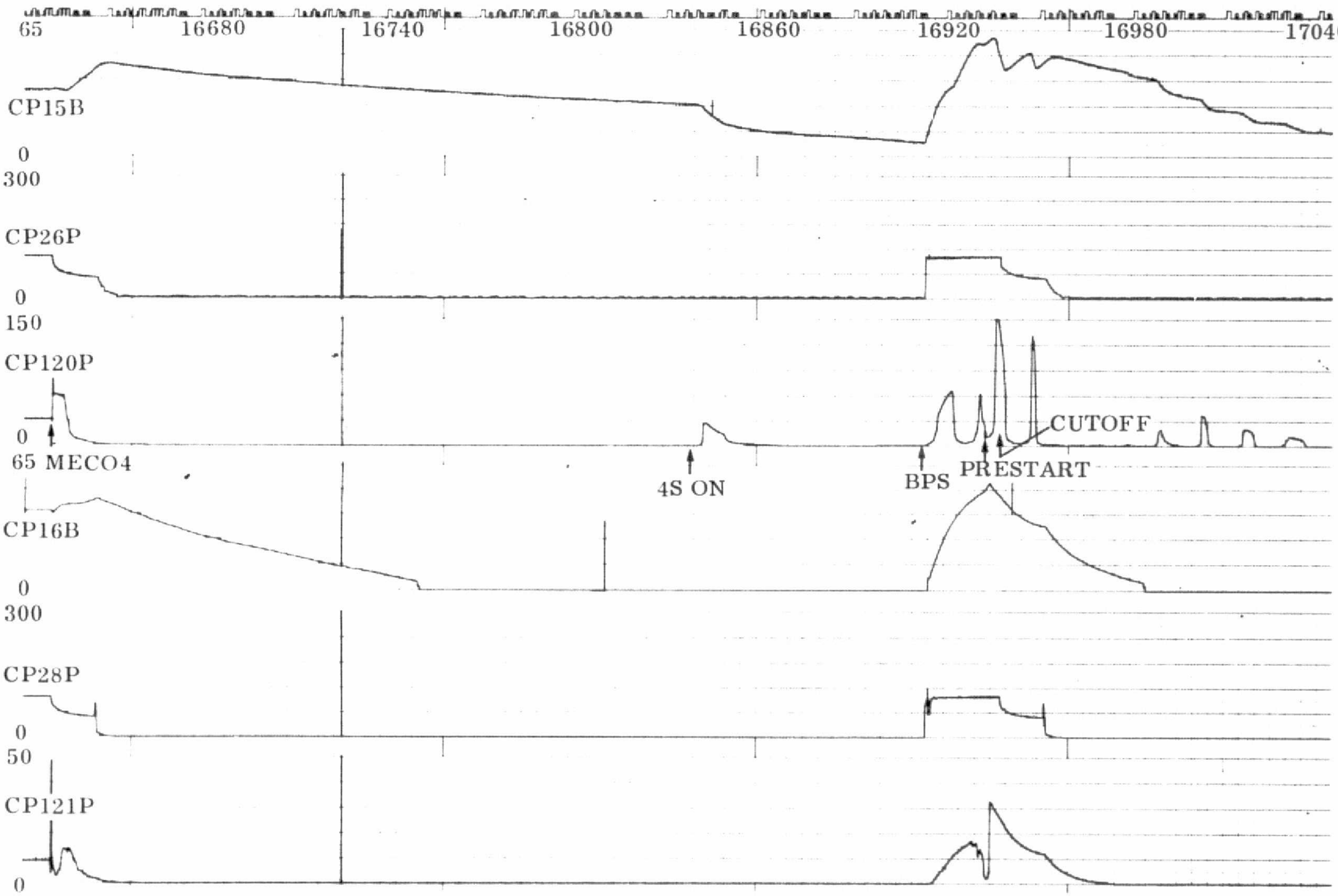
POST MECO4 BOOST PUMP PERFORMANCE



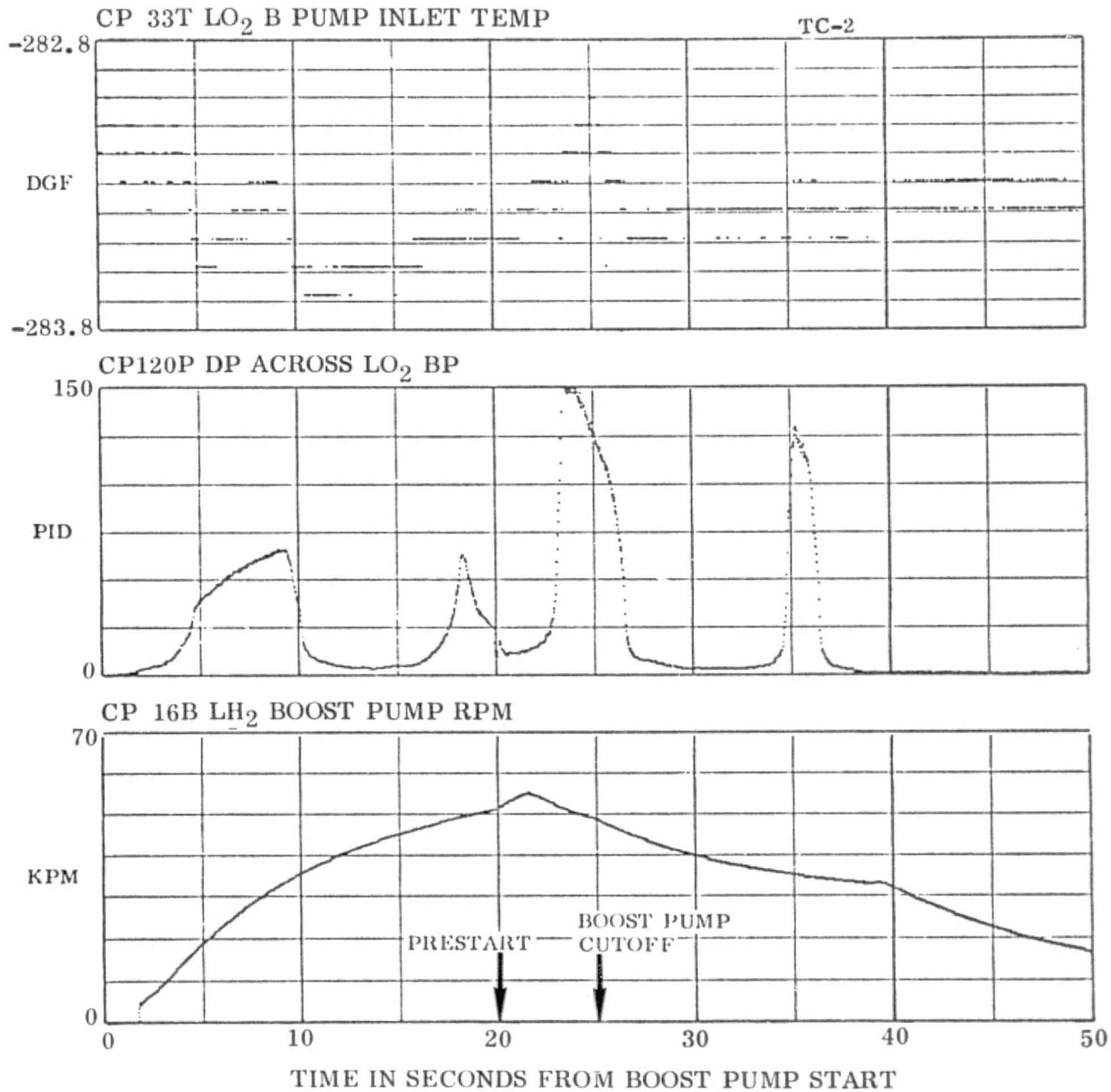
LO_2 BOOST PUMP PERFORMANCE (EXPERIMENT)

- THE PUMP CAVITATED UNTIL BPS +4.5 SECONDS AND THEN PUMPED LIQUID UNTIL BPS +9.5 SECONDS.
  - ▲ A HIGH VAPOR CONCENTRATION WAS PRESENT AT THE PUMP AT BPS.
  - ▲ CAVITATION AT BPS +9.5 SECONDS WAS PROBABLY CAUSED BY THE VOLUTE FLOW (MOMENTUM INPUT WAS ABOUT 600 LB-$\frac{FT}{SEC}$).
- PUMP LOADING AND UNLOADING PERSISTED UNTIL BOOST PUMP CUTOFF +100 SECONDS.
- BOOST PUMP INLET TEMPERATURES INDICATED COOLING AND HEATING TRENDS OF 0.5°F (MAX) AND 0.7°F (MAX), RESPECTIVELY.
- LO_2 TANK PRESSURE INCREASED BY 0.2 PSID DURING THE EXPERIMENT.

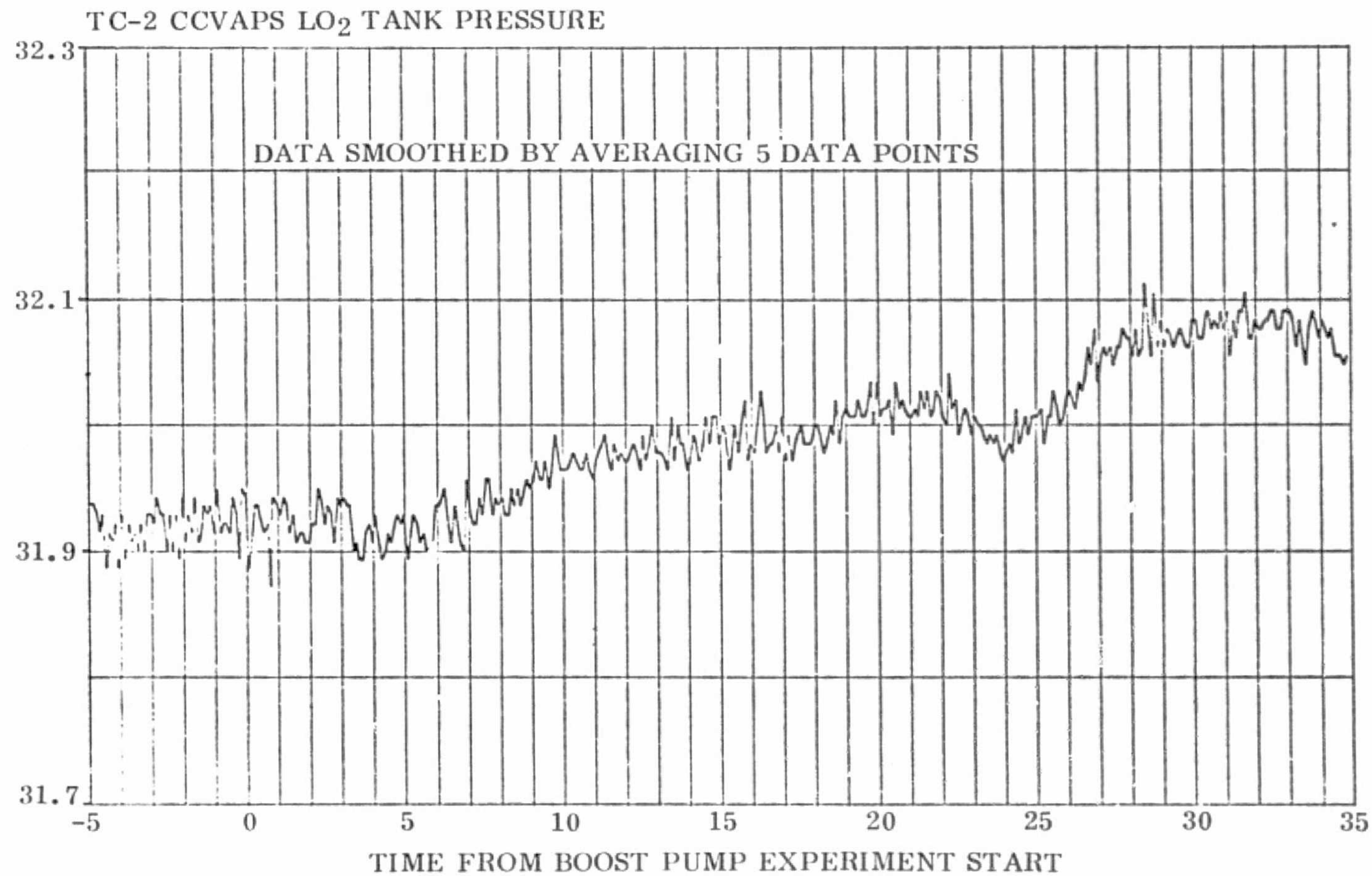
CONCLUSIONS

- VOLUTE RETURN FLOW RESPONSIBLE FOR PUMP CAVITATION.
- FOR FUTURE MISSIONS CAVITATION WILL BE A CONCERN FOR ENGINE STARTS AT LOW LIQUID LEVELS.

BOOST PUMP EXPERIMENT – LO_2 UNIT



LO_2 TANK PRESSURE DURING BOOST PUMP EXPERIMENT



TC-5 IMPLICATIONS

LH_2 TANK

- THE LH_2 BOOST PUMP IS EXPECTED TO PERFORM SATISFACTORILY FOR ALL RESTARTS. THE EXPERIMENT DEMONSTRATED THAT SATISFACTORY PUMP PERFORMANCE IS POSSIBLE WITH NO PREPRESSURIZATION.

LO_2 TANK

- CAVITATION WILL BECOME AN INCREASING CONCERN FOR THE LATER MAIN ENGINE STARTS. POTENTIAL FLUID CONDITIONS WITHIN THE THRUST BARREL ARE GIVEN BELOW:

EVENT	LH_2 MASS LB	PERCENT VAPOR VOL.	ΔP REQUIRED FOR BUBBLE COLLAPSE, PSID
MES4	1285	13	0.36
MES5	987	33	1.21
MES6	876	40	1.61
MES7	721	51	2.51
		TC-2	
MES4 (TC-2)	1421	3.7	0.12

TC-2 POST HELIOS EXPERIMENT DATA REVIEW

I	INTRODUCTION	HUBER
II	PROPELLANT BEHAVIOR	MERINO
III	HELIUM USAGE	MERINO
IV	PROPELLANT TANK PRESSURIZATION	MERINO
V	PROPELLANT TANK THERMODYNAMICS	MERINO
VI	COMPONENT HEATING & THERMAL CONTROL	CHRISTENSEN
VII	MAIN ENGINE SYSTEM	HUBER
VIII	H_2O_2 CONSUMPTION	HUBER
IX	BOOST PUMP POST-MECO PERFORMANCE	HUBER/MERINO
X	OVERVIEW OF OTHER SYSTEMS	HUBER

OVERVIEW OF OTHER SYSTEMS

- PROPELLANT UTILIZATION SYSTEM
- HYDRAULIC SYSTEM
- GUIDANCE AND CONTROL
- ELECTRICAL SYSTEM
- RF AND INSTRUMENTATION
- PNEUMATICS SYSTEM

PROPELLANT UTILIZATION

DURING THIRD BURN THE PU VALVES WERE KEPT AT NULL BECAUSE OF THE SHORT BURN DURATION OF 11 SECONDS.

DURING FOURTH BURN THE VALVES MOVED TO THE CLOSED LIMIT SOON AFTER UNNULLING AND REMAINED AT THIS LIMIT UNTIL MECO. THIS WAS DUE TO A LARGE FUEL-RICH ERROR AT THE START OF FOURTH BURN. THE SYSTEM WOULD HAVE REQUIRED AN ADDITIONAL 40 TO 50 SECONDS OF ENGINE OPERATION TO CORRECT OUT THIS ERROR.

FOURTH BURN PROPELLANT RESIDUAL

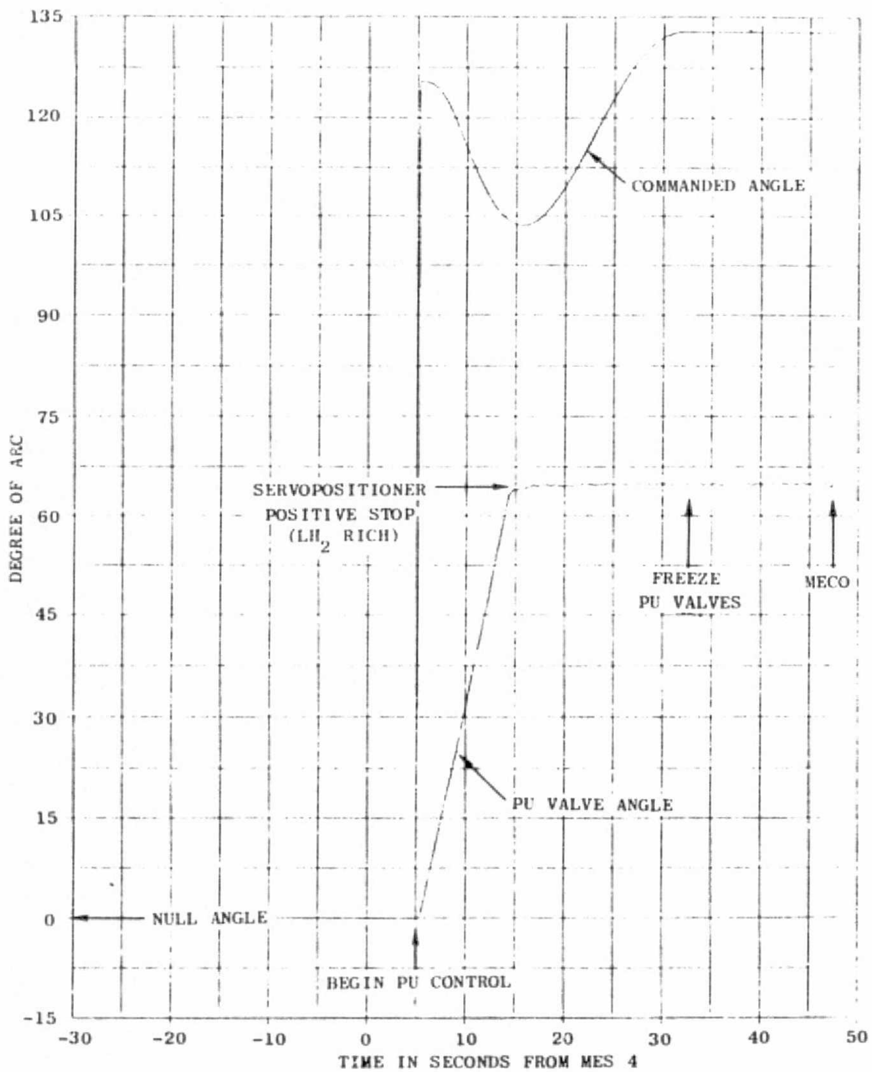
TOTAL LO_2 (LB)		TOTAL LH_2 (LB)	
PREDICTED	ACTUAL	PREDICTED	ACTUAL
725	791*	195	303†

* ACTUAL LO_2 RESIDUAL WAS BASED UPON LO_2 PU PROBE UNCOVERY TIME OF MECO-5.02 SECONDS.

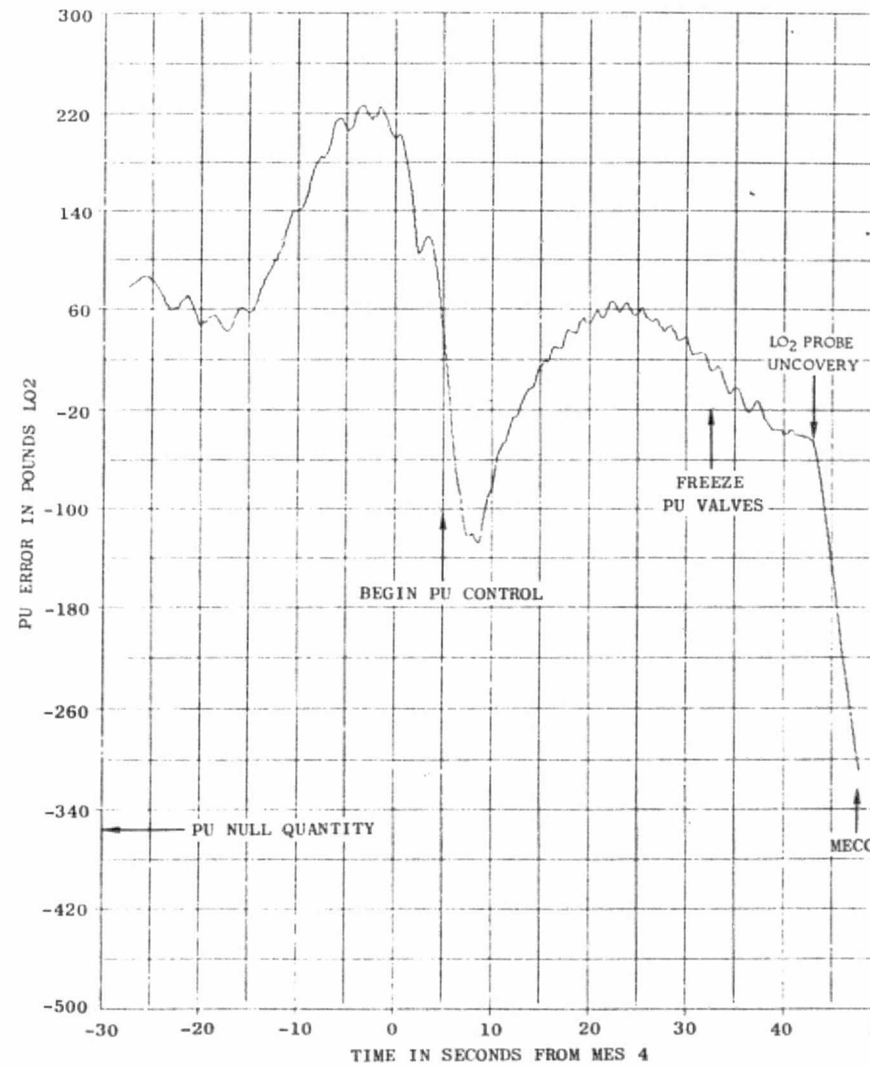
† SINCE LH_2 PROBE DID NOT UNCOVER, ACTUAL RESIDUAL WAS CALCULATED FROM THE PU ERROR SIGNAL BASED UPON TIME OF LO_2 PROBE UNCOVERY.

FOURTH BURN PROPELLANT UTILIZATION OPERATION

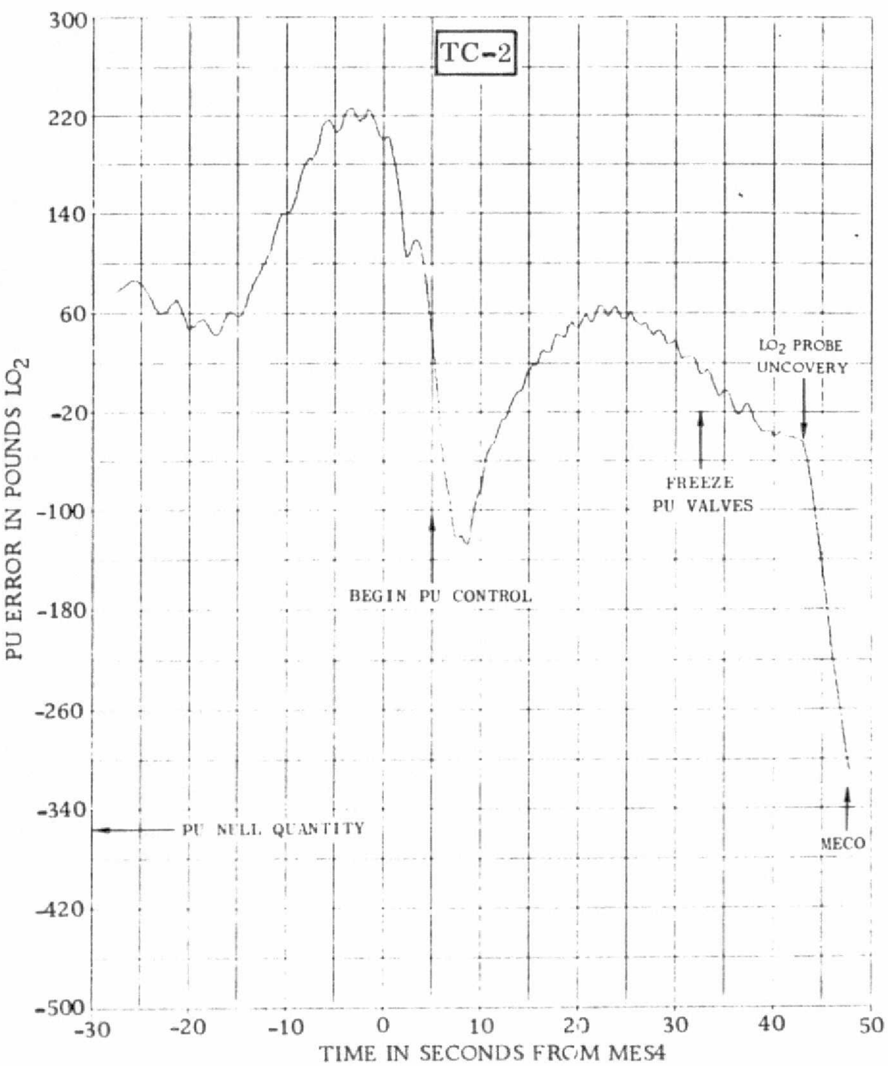
C-1 PU VALVE ANGLE VERSUS COMMANDED ANGLE

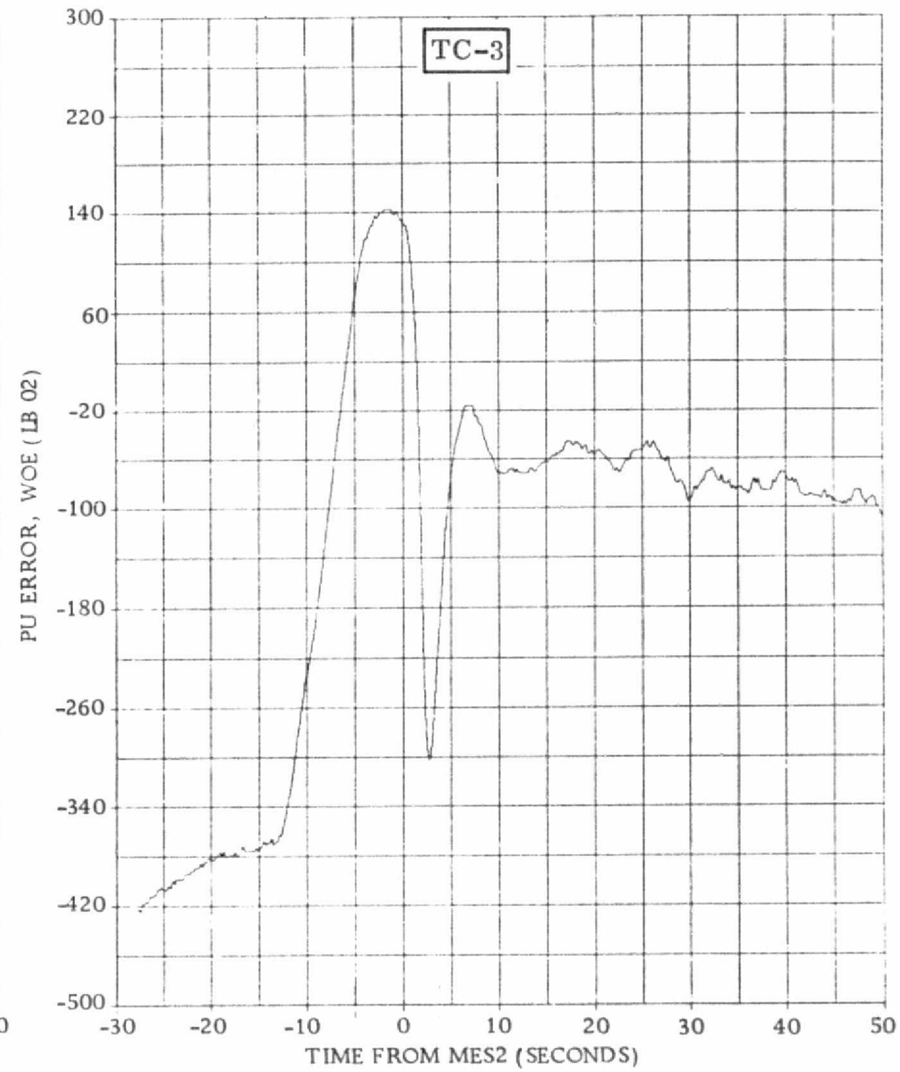


PU ERROR SIGNAL



POST-SETTLED COAST BURN 2 PU ERROR SIGNAL





OVERVIEW OF OTHER SYSTEMS

- PROPELLANT UTILIZATION SYSTEM
- HYDRAULIC SYSTEM
- GUIDANCE AND CONTROL
- ELECTRICAL SYSTEM
- RF AND INSTRUMENTATION
- PNEUMATICS SYSTEM

HYDRAULIC SYSTEM

- THE HYDRAULIC SYSTEM PROVIDED SATISFACTORY C1 AND C2 PRESSURES DURING THE 3RD AND 4TH BURNS AND DURING PERIODS OF RECIRCULATION PUMP OPERATION.

STEADY STATE HYDRAULIC POWER PACKAGE PRESSURES (PSIA)

	RECIRCULATION PUMP		ENGINE PUMP			
	PRE-MES3	PRE-MES4	MES3 + 2 SEC	MECO3	MES4 + 2 SEC	MECO4
C1 POWER PACK	142	142	1132	1132	1147	1132
C2 POWER PACK	142	142	1147	1147	1147	1147

- THE C2 RECIRCULATION PUMP WAS ACTIVATED 4 TIMES BY THERMOSTAT CONTROL (10 ± 6 DGF) NEAR THE END OF THE 3-HR COAST FOR PERIODS OF 28, 5, 6, AND 5 SECONDS. DE-ACTIVATION (EXPECTED AT 30 ± 6 DGF) OCCURRED WITHOUT SIGNIFICANT RISE OF THE MANIFOLD TEMPERATURE (CH6T). INVESTIGATION REVEALED THIS TO BE NORMAL BEHAVIOR OF THE THERMOSTAT CONTROL WHEN SUBJECTED TO A SHALLOW TEMPERATURE GRADIENT.

OVERVIEW OF OTHER SYSTEMS

- PROPELLANT UTILIZATION SYSTEM
- HYDRAULIC SYSTEM
- GUIDANCE AND CONTROL
- ELECTRICAL SYSTEM
- RF AND INSTRUMENTATION
- PNEUMATICS SYSTEM

THE DIGITAL COMPUTER UNIT (DCU) HARDWARE/SOFTWARE PERFORMANCE WAS SATISFACTORY

- SCU SWITCH COMMANDS WERE GENERATED IN CORRECT SEQUENCE WITH NO INADVERTENT COMMANDS.
- D/A OUTPUT AND A/D INPUT CONVERSIONS WERE PERFORMED WITHOUT INCIDENT.
- ALL SOFTWARE MODULES PERFORMED SATISFACTORILY.
- PERMANENT MEMORY CHECKSUM VALUE REMAINED CONSTANT.
- CCU FORMATTING OF PCM AND DCU DATA WAS SATISFACTORY.

NAVIGATION AND GUIDANCE FUNCTIONS PERFORMED AS PLANNED

- NAVIGATION (POSITION AND VELOCITY) PROVIDED CONTINUOUSLY THROUGH ALL COAST AND POWERED PHASES.
- CENTAUR ORIENTED TO -R VECTOR (PLUS 1 DEGREE) DURING THIRD COAST AND MAINTAINED THERE FOR REST OF FLIGHT.
- ALL SIX THERMAL ROLLS DURING THIRD COAST PERFORMED AT 28-MINUTE INTERVALS AS PLANNED.
- BOTH BURNS WERE UNGUIDED WITH:
  1. INTEGRAL CONTROL USED AFTER MES3 +7 SECONDS DURING THIRD BURN.
  2. INTEGRAL CONTROL PLUS GUIDANCE ATTITUDE VECTOR USED AFTER MES4 +7 SECONDS DURING FOURTH BURN.
- ALL ENGINE START AND CUTOFF TIMES WERE CLOSE TO NOMINAL. MECO4 WEIGHT CUTOFF CALCULATIONS WERE SATISFACTORY.
- IMG U, V, W ACCELEROMETER BIAS ERRORS DURING COAST BETWEEN 3RD AND 4TH BURNS WERE 42, 72, AND -30 μG, RESPECTIVELY (3-SIGMA ERROR VALUE WAS 144 μG).

CENTAUR ORBITS

PARAMETER	THIRD BURN ORBIT			FOURTH BURN ORBIT		
	PALTT*	GUIDANCE †	DIFFER-ENCE ‡	PALTT*	GUIDANCE †	DIFFER-ENCE ‡
EPOCH (SEC)	5,788	5,792	+4	16,636.5	16,650.0	+ 13.5
PERIGEE ALT (NM)	200.4	208.7	+8.3	851.9	951.8	+ 99.9
APOGEE ALT (NM)	——	——	——	81,474.2	85,597.4	+123.2
SMA (NM)	-34,760	-34,699	+61	44,607	46,718	+111
ECC	1.104842	1.105268	+0.000426	0.903697	0.905910	+ 0.002213
INCLINATION (DEG)	29.815	29.918	+0.103	29.815	31.764	+ 1.949
ARG OF PERIGEE (DEG)	230.451	230.602	+0.151	215.651	216.232	+ 0.581
C3 (KM^2/SEC^2)	6.19	6.20	+0.01	-4.82	-4.61	+ 0.21
TRUE ANOMALY (DEG)	114.703	114.641	-0.062	151.989	151.066	- 0.923

* GDC PRELAUNCH ACTUAL LAUNCH TIME TRAJECTORY.

† TELEMETERED DATA.

‡ GUIDANCE MINUS PALTT.

THIRD AND FOURTH BURN ORBIT INCLINATION DIFFERENCES

- THIRD AND FOURTH BURN ORBITAL INCLINATIONS WERE 0.1 AND 1.95 DEG GREATER THAN PALTT VALUES.
- NOT A PROBLEM AS GUIDANCE WAS OPEN LOOP AND PRECISE ORBITS WERE NOT REQUIRED.
- DIFFERENCES ATTRIBUTED TO OUT-OF-PLANE VELOCITIES DUE TO C.G. OFFSETS, THRUST MISALIGNMENTS, AND GUIDANCE HARDWARE ERRORS (RESOLVER CHAIN AND ASSOCIATED ELECTRONICS).
- POSTFLIGHT ANALYSIS INDICATES C.G. OFFSET WAS THE MAIN CONTRIBUTOR.

COAST PHASE AUTOPILOT

- THE ATTITUDE CONTROL SYSTEM MAINTAINED VEHICLE STABILITY SATISFACTORILY AT OR WITHIN THE CONTROL THRESHOLDS THROUGHOUT THE COAST PHASES.

- ALIGNMENT TO -1_R VECTOR STARTED AT MECO2 + 116 SECONDS (MAXIMUM RATE 0.1 DEGREES/SECOND) AND WAS MAINTAINED THROUGHOUT THE REMAINDER OF MISSION.

TYPICAL 0-G AVERAGE ATTITUDE CONTROL ENGINE DUTY CYCLES

CONTROL AXIS	AVERAGE DUTY CYCLES (%)*		CONTROL THRESHOLDS		MINON (SEC)
	POSITIVE	NEGATIVE	RATE (DEG/SEC)	ATTITUDE (DEG)	
PITCH	0.08	-0.064	1.2	9.6	0.4
YAW	0.08	-0.096	1.2	9.6	0.4
ROLL	0.036	-0.036	2.25	9.0	0.1

* TYPICAL MEASURED DURING 1-HR COAST (2565 TO 3845 AND 4135 TO 5340 SECONDS).

- 180-DEGREE THERMAL ROLL MANEUVERS WERE ACCOMPLISHED SATISFACTORILY EVERY 28 MINUTES DURING THE 3-HR COAST AT A 2-DEGREES/SECOND RATE.

POWERED PHASE AUTOPILOT

- STABILITY WAS MAINTAINED THROUGHOUT THE THIRD AND FOURTH BURNS.
- MAXIMUM ENGINE DEFLECTIONS WERE 1.3 DEGREES (3RD BURN) AND 1.6 DEGREES (4TH BURN) DURING THE START TRANSIENTS.
- START TRANSIENT INDUCED RATES LARGER THAN USUAL DUE TO LACK OF PAYLOAD.

MAXIMUM ATTITUDE AND RATE ERRORS DURING START TRANSIENTS

	TC-2 3RD BURN		TC-2 4TH BURN		AC-31,32,34,35,36 & TC-2 2ND BURN
CONTROL AXIS	MAX ATTITUDE ERROR (DEG)	MAX RATE (DEG/SEC)	MAX ATTITUDE ERROR (DEG)	MAX RATE (DEG/SEC)	AVG. MAX RATE (DEG/SEC)
PITCH	-5.2	-8.0*	-5.8	-9.3*	-0.83 ± 8.82
YAW	+1.6	+0.3	+2.7	+1.2	-0.19 ± 1.68
ROLL	-1.6	-4.2	-2.5	-4.7	-2.87 ± 3.36

*PREDICTED WORST CASE RATE MAXIMUM = -24.5 DEG/SEC.

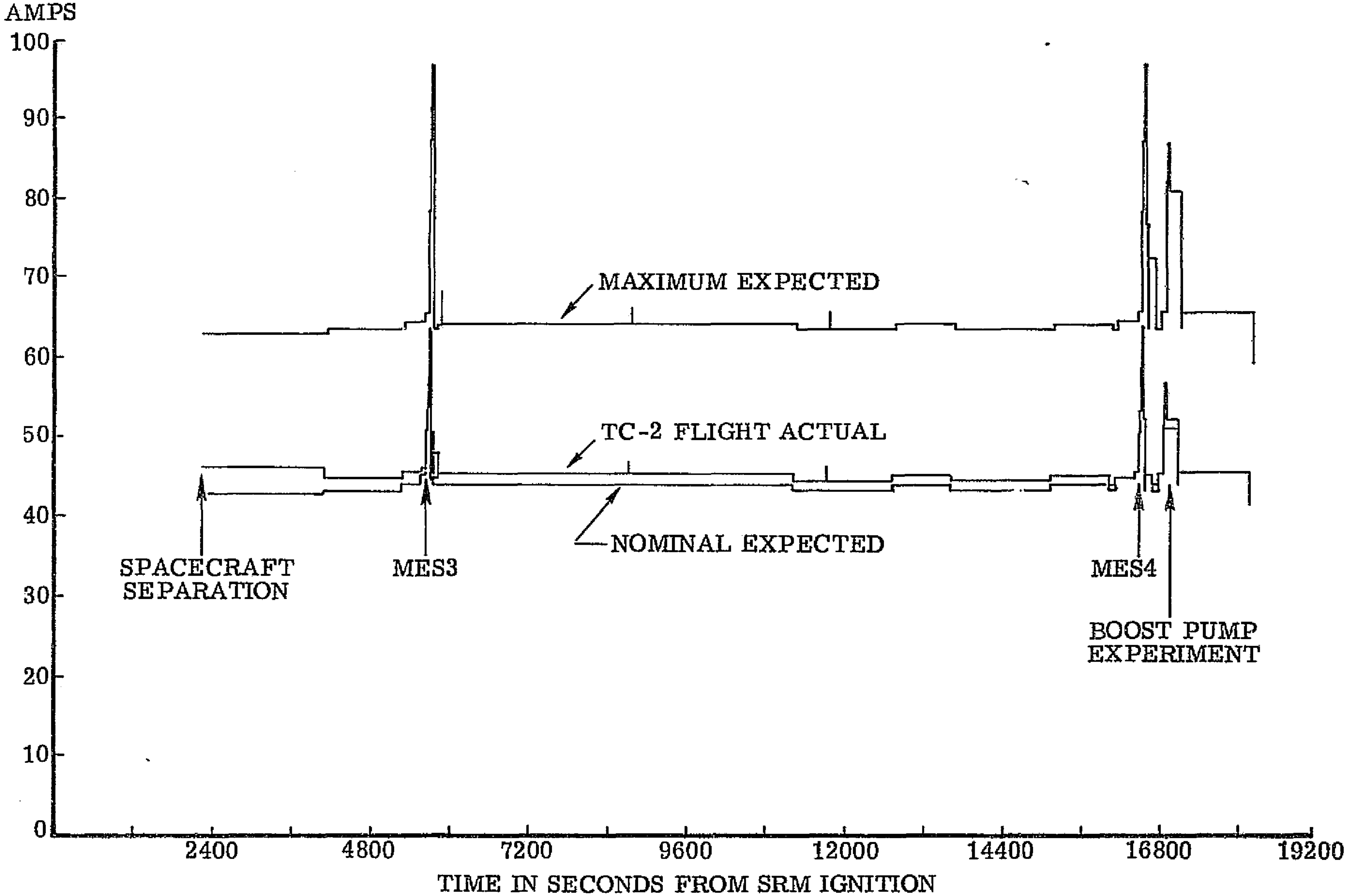
OVERVIEW OF OTHER SYSTEMS

- PROPELLANT UTILIZATION SYSTEM
- HYDRAULIC SYSTEM
- GUIDANCE AND CONTROL
- ELECTRICAL SYSTEM
- RF AND INSTRUMENTATION
- PNEUMATICS SYSTEM

ELECTRICAL SYSTEM VOLTAGES

MEAS. NO.	DESCRIPTION	UNITS	T-0	S/C SEP	MES3	MECO3	MES4	MECO4	LOS (18,960 SEC)	EXPECTED RANGE
CE28V	BUS 1 VOLTAGE	VDC	28.3	28.3	28.5	28.5	28.8	28.8	29.0	28.0 MIN @ LIFTOFF 28.0 ± 2 VDC INFLIGHT
CE600V	BATT 1 VOLTAGE	VDC	28.3	28.3	28.5	28.6	28.9	28.9	28.9	
CE609V	BATT 2 VOLTAGE	VDC	29.0	28.7	28.6	28.6	28.9	29.0	30.0	
CE610V	BATT 3 VOLTAGE	VDC	28.7	28.4	27.9	29.0	28.3	29.1	29.1	28.0 MIN @ LIFTOFF 28.0 ± 2 VDC INFLIGHT

CURRENT PROFILE (CEIC) WAS CLOSE TO EXPECTED



OVERVIEW OF OTHER SYSTEMS

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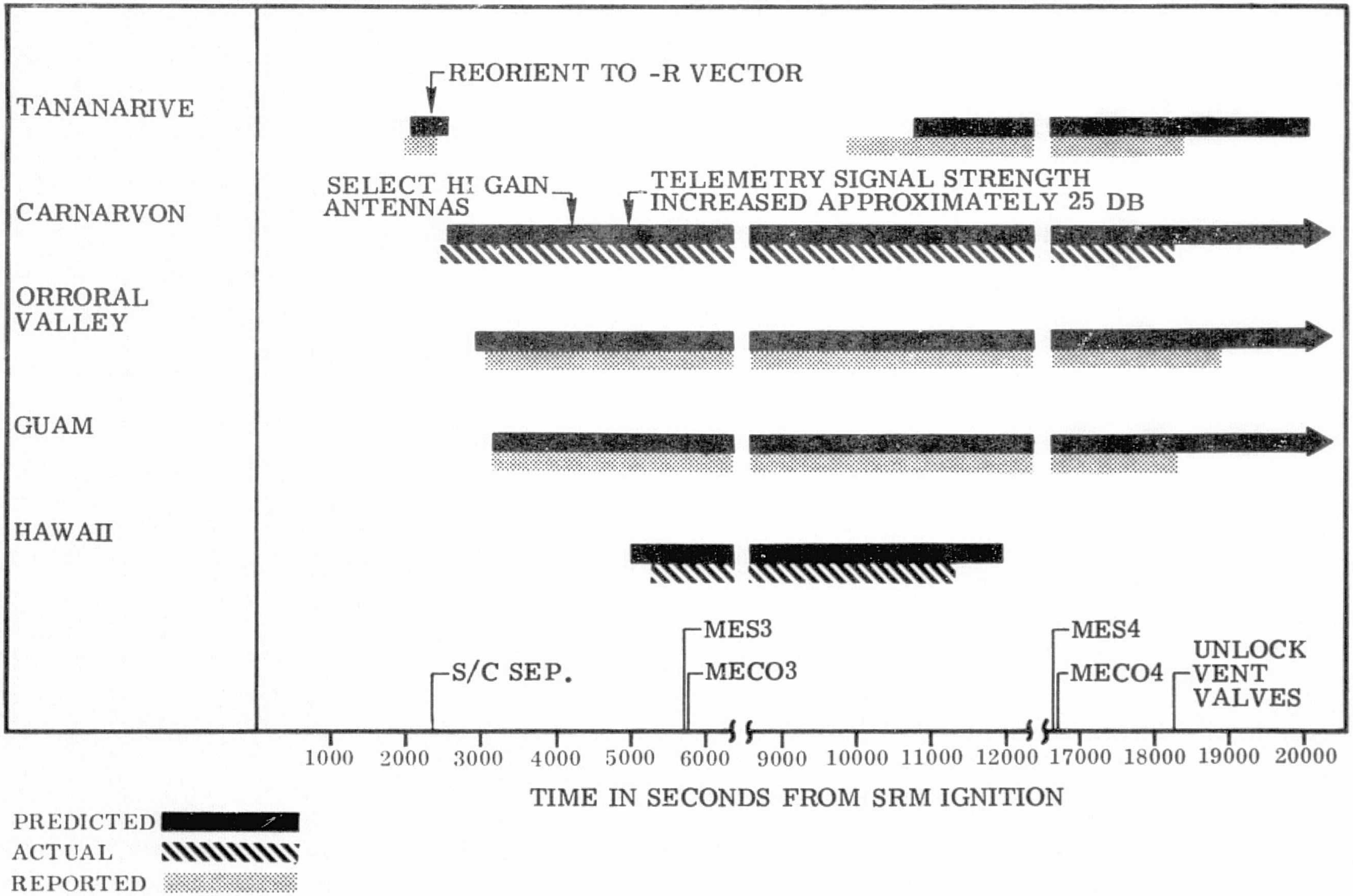
TELEMETRY DATA COVERAGE WAS CONTINUOUS THROUGHOUT THE POST-HELIOS EXPERIMENT PHASE



INSTRUMENTATION SYSTEM

TOTAL MEASUREMENTS INSTRUMENTED		569
PCM	523	
FM/FM	23	
24 BIT DCU WORDS	23	

99.5% DATA RECOVERY WAS ADEQUATE FOR EVALUATION OF ALL POST-HELIOS EXPERIMENT PHASE OBJECTIVES.

C-BAND BEACON RADAR TRACKING SYSTEM

STATION/RADAR	AQUISITION OF SIGNAL (SEC)	LOSS OF SIGNAL (SEC)	MODE*	COMMENTS
CAP CANAVERAL/1.16	0	375	AB	The beacon was tracked continuously by one or more radar stations until loss-of-signal (LOS) at Antigua (762 seconds).
MERRITT ISLAND/19.18	10	492	AB	
GRAND BAHAMA ISLAND/3.13	69	86	AB	
	86	270	OAPFB	Following Antigua LOS, no tracking of the Centaur beacon was planned until acquisition-of-signal (AOS) by the Hawaii radar (5,333 seconds). The preflight RF link analysis had indicated that tracking by the Hawaii radar and subsequently by the Canton Island radar would be marginal due to the extreme slant range. The Hawaii station did report tracking the beacon but experienced difficulties and significant loss of data.
	270	272	OAPFS	
	272	299	AS	
	299	311	AB	
	311	316	OAPFB	
	343	365	AB	
	368	513	OAPFB	
GRAND TURK/7.18†	259	350	AB	
ANTIGUA/91.18	407	762	AB	
HAWAII/FPS-16	5,333	10,786	AB	The Canton Island station reported receiving no valid tracking data as the wrong range interval was being used.
CANTON ISLAND	6,240	6,600	AB	
	7,567	7,800	AB	
	8,220	8,400	AB	
	8,576	8,636	AB	

*MODE OF TRACK: AB - AUTOBEACON
AS - AUTOSKIN
OAPFB - ON-AXIS POWERED FLIGHT BEACON
OAPFS - ON-AXIS POWER FLIGHT SKIN

†SWITCHED TO TE-M-364-4 BEACON AT 350 SECONDS.

‡INTERMITTENT TRACK DURING THIS PERIOD.

OVERVIEW OF OTHER SYSTEMS

- PROPELLANT UTILIZATION SYSTEM
- HYDRAULIC SYSTEM
- GUIDANCE AND CONTROL
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- RF AND INSTRUMENTATION
- PNEUMATICS SYSTEM

PNEUMATIC SYSTEM

- PROPER H_2O_2 BOTTLE PRESSURES PROVIDED THROUGHOUT FLIGHT.
- TANK PRESSURES MAINTAINED WITHIN EXPECTED LIMITS DURING ALL PRESSURIZATION AND VENT PHASES.
- ENGINE CONTROL PRESSURE WAS MAINTAINED WITHIN PROPER LIMITS THROUGH THE FINAL BURN.
- STARTING 480 SECONDS AFTER MECO4 THE ENGINE CONTROL PRESSURE EXHIBITED ABNORMAL FLUCTUATIONS.

ENGINE CONTROLS REGULATOR ANOMALY

ANOMALY

Regulator output pressure increased from 468 psi to 522 psi. Regulator operating limits are 440 to 475 psi.

MOST LIKELY CAUSE

Small contaminant (25μ thick) trapped between a ball and its seat within the regulator, preventing the ball from seating properly, thus increasing helium flow.

DISCUSSION

Regulator inlet pressure of 628 psi insufficient to crush contaminant. Inlet spec. is 700 to 3360 psi. The consequences of a repeat on a future flight are considered negligible.

ENGINE CONTROLS REGULATOR OUTLET PRESSURE